NASA TECHNICAL MEMORANDUM

NASA TM X-1525

NASA TM X-1525

INSTRUMENTATION OF A SNAP-8 SIMULATOR FACILITY

by James N. Deyo and William T. Wintucky

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MARCH 1968

NASA TM X-1525

INSTRUMENTATION OF A SNAP-8 SIMULATOR FACILITY

By James N. Deyo and William T. Wintucky

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – CFSTI price $3.00

INSTRUMENTATION OF A SNAP-8 SIMULATOR FACILITY

by James N. Deyo and William T. Wintucky

Lewis Research Center

SUMMARY

The philosophy and experience with high-temperature (up to 1300° F (1000° K)) instrumentation, pressure sensors, thermocouples, and flowmeters are discussed. Secondary and support instrumentation in the test facility and control room are also included. The approach described is based on the parameters to be measured as well as the time schedule, physical characteristics, and available instrumentation for the facility. The results include data handling, accuracy, and reliability of the system. Over 2000 hours of operation were accumulated, during which time the mercury loop was at operating temperature for about 1000 hours. More than 2000 data runs were taken.

INTRODUCTION

The SNAP-8 liquid-metal Rankine cycle power-conversion system is an electrical source under development for continuous high power output in space. This type of system, utilizing nuclear energy as its heat input, is complex because of the integration of many dynamic components and subsystems. To ensure required performance and reliability for long-term operation, it is necessary to do multiple testing of each component and of the complete system. In order to test the components and systems, a test facility must first be built and instrumented.

A test facility at the NASA Lewis Research Center was constructed and instrumented to simulate the three liquid-metal loops of the SNAP-8 power-generating system. The primary NaK (eutectic mixture of sodium-potassium) loop contained a reactor simulator which consisted of a NaK electric heat controlled by an analog computer. High-temperature NaK flowed to a boiler where the power-conversion loop mercury was vaporized. The mercury was condensed in a NaK-cooled SNAP-8 condenser. In the heat-rejection loop, the condenser was coupled with two NaK-to-air heat exchangers which with the analog computer simulated a space radiator.

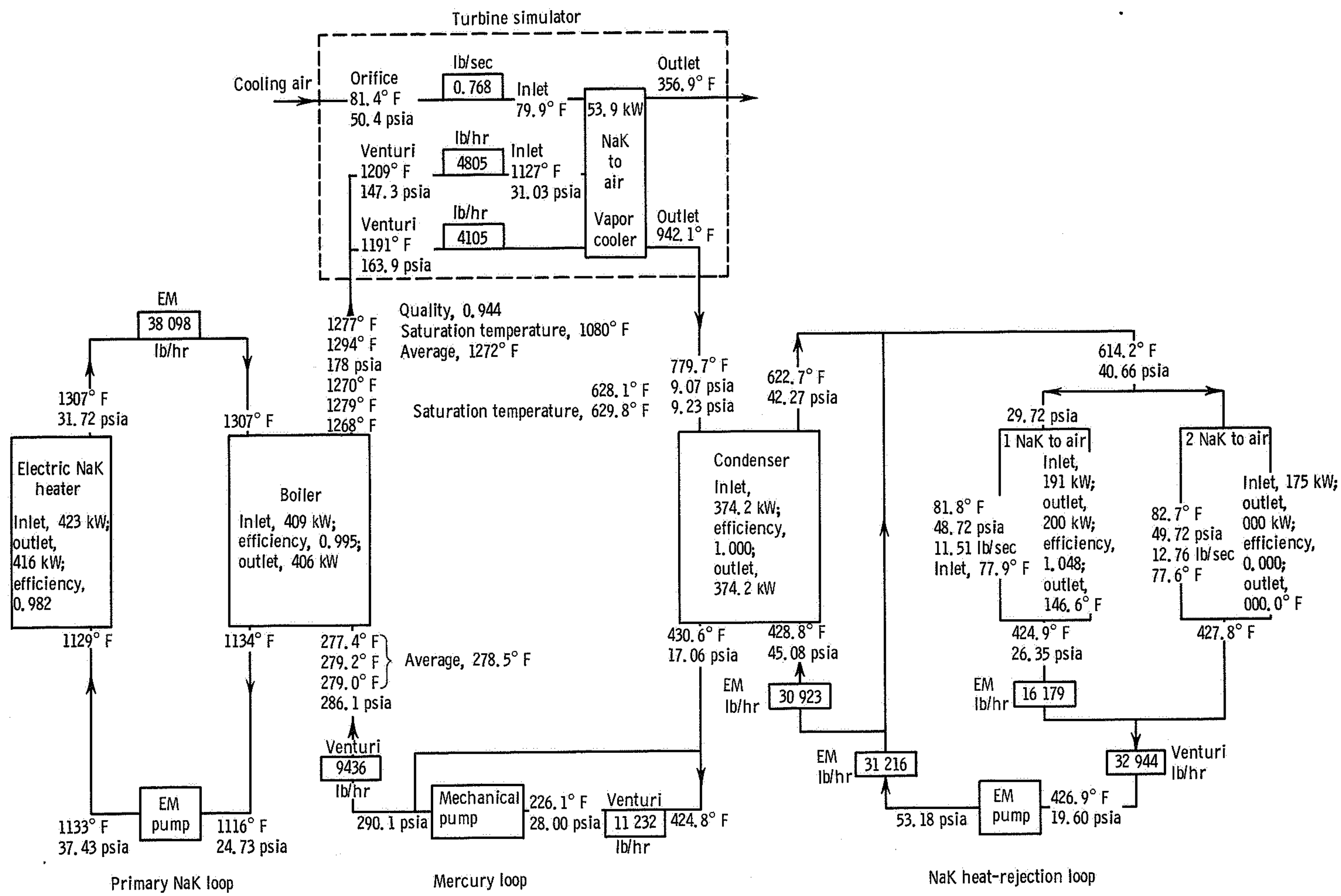
The instrumentation and data handling techniques used in the facility with the simulated SNAP-8 system are discussed in this report. System simulation, components, and subsystems are briefly described. Types of general and special instrumentation as well as data are presented. A detailed discussion of sensor selection, installation, signal conditioning, and calibration techniques are covered. Data recording, handling, and output along with typical accuracies are discussed. Because of its size and complexity, the associated control room is discussed in detail. The information presented includes general philosophy and instrument criteria which can be useful as a guide in instrumenting any liquid-metal or complex test facility.

TEST FACILITY

The SNAP-8 simulator test facility was designed to duplicate as closely as practical the actual SNAP-8 system. This system is reported in detail in reference 1. Figures 1 and 2 show the basic simulator schematic drawing and component arrangement. The primary NaK loop has an electric heater to take the place of a nuclear reactor in which NaK is heated (refs. 2 and 3). Heated NaK then passes through a commercial electromagnetic (EM) flowmeter where the volume flow is measured before it flows into a SNAP-8 tube-in-shell boiler (ref. 4). In the boiler, the NaK gives up some of its heat and then is pumped back into the heater through an electromagnetic (EM) pump. The power-conversion loop (mercury loop) uses mercury as the working fluid. In the boiler, mercury is vaporized and superheated and then passes into the turbine simulator. The simulator duplicates the energy conversion of the turbine by taking the pressure drop through several valves and venturis and removing heat in a vapor cooler (mercury-to-air heat exchanger). Mercury vapor is then completely condensed to the liquid state in a SNAP-8 condenser (ref. 5) after which it passes through a commercial rotary pump. From the pump, an electrohydraulically actuated valve (not shown) controlled flow to a calibrated venturi where the weight flow rate was measured before it went back to the boiler.

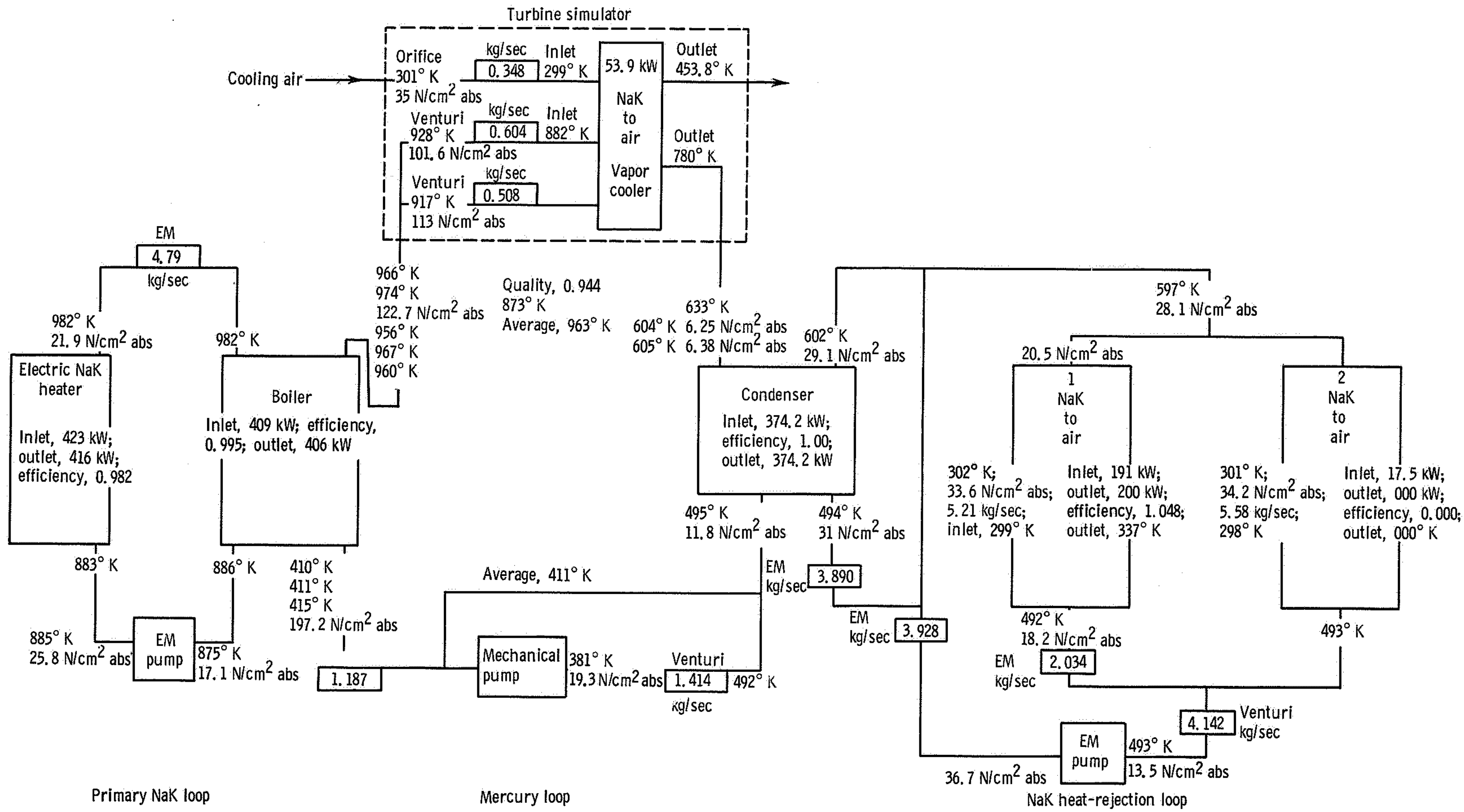
The heat-rejection loop (secondary NaK loop) fluid NaK-78 removed heat from the mercury in the condenser. The NaK then transferred this heat out of the system in two NaK-to-air heat exchangers (radiators (ref. 6)). NaK flow was measured through a calibrated venturi and several EM flowmeters and was pumped around the loop by a commercial EM pump.

Figure 2 shows the general arrangement of the components in the test cell. Within the inner enclosure, which closely contains the experiment, there was insufficient room to place instrumentation sensors and transmitters freely. To reduce heat losses from the experiment and keep the environmental temperature down for the instrumentation, all components and connecting pipes had 4 to 6 inches (10 to 15 cm) of insulation depending



(a) U. S. customary units.

Figure 1. - Basic simulator system schematic drawing and general system performance in computer output format.



(b) SI units.

Figure 1. - Concluded.

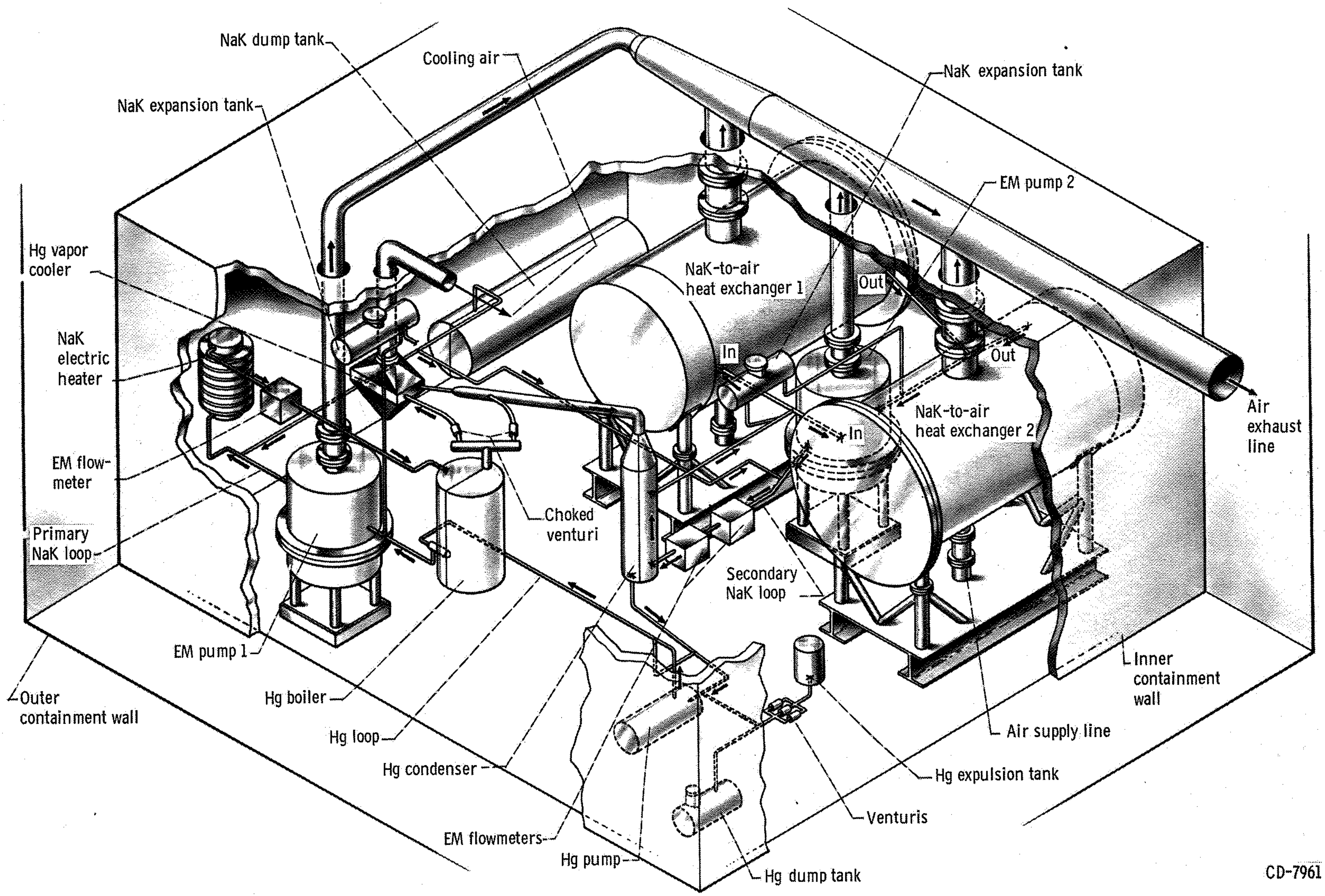
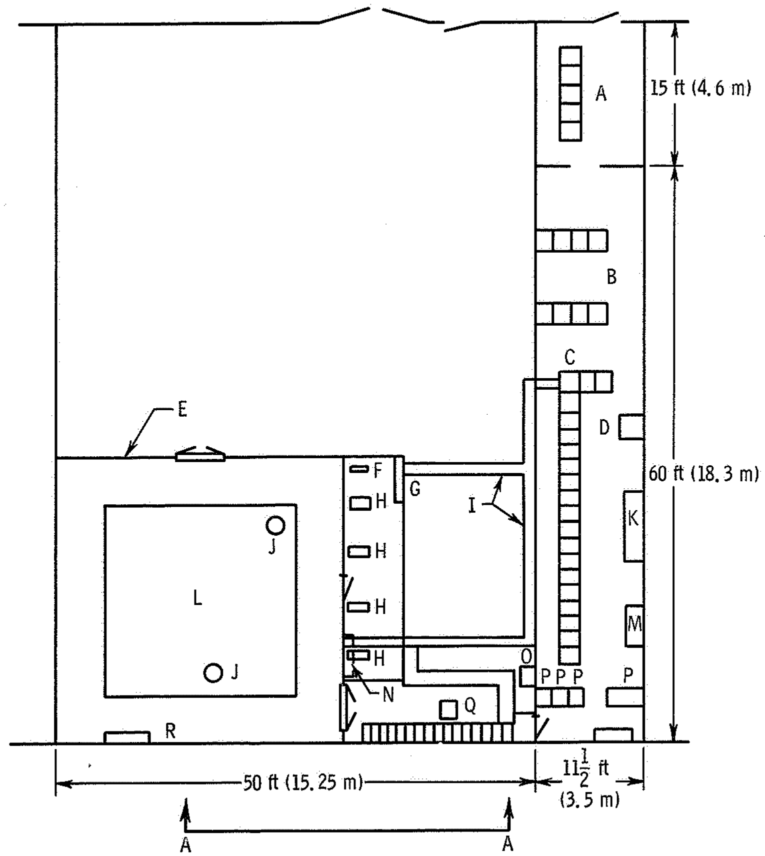
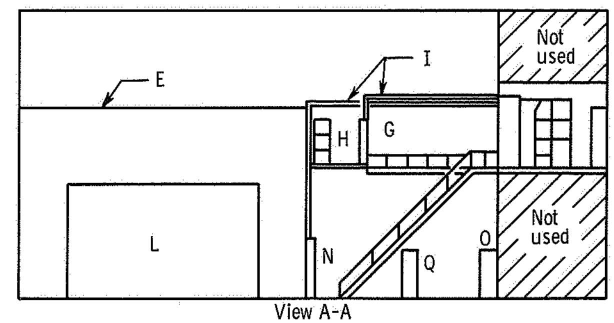


Figure 2. - General arrangement of components in test enclosure of SNAP-8 simulator.





L, Inner test enclosure (20 by 20 by 12 ft (6.1 by 6.1 by 3.66 m)) (inerted with N_2 during operation)
J, Television monitoring cameras
E, Outer test enclosure (30 by 30 by 20 ft (9.15 by 9.15 by 6.1 m)) (inerted with N_2 during operation)
Q, Oxygen analyzer
O, Mercury vapor detector
N, Instrumentation sensor junction box
G, Thermocouple junction box
H, Thermocouple reference ovens
I, Instrumentation cable trays
R, Test enclosure "air" conditioner for nitrogen cooling during inerting
B, Control room ($11\frac{1}{2}$ by 60 ft) (3.5 by 18.3 m))
A, Cadde field relay station
C, Control-room junction box for all instrumentation
F, Thermocouple patchboard
D, Cadde typeback unit
M, 48-Point alarm system
P, Analog computer
K, Table

Figure 3. - Plan and elevation views of SNAP-8 simulator facility.

on the temperature level. Many of the longer pipes were heated by resistance heater elements strapped along their entire length. Resistance heater wire was wound around the irregular shapes. Normally, heater temperature was regulated by automatic controllers. However, when data were being taken, the heater elements were turned off.

Figure 3 shows the plan and elevation view of the test facility and the physical relations of the experiment, control room, and various instrumentation stations. Safety and available space dictated the arrangement of the facility. The control-room shape did not lend itself to rapid monitoring of the extensive instrumentation and controls.

GENERAL INSTRUMENTATION CONSIDERATIONS

The goals, established at the conception of the facility, provided the ground rules for its design and instrumentation. The major objectives of the tests performed in this facility were to obtain the following information:

(1) The performance of each component and simulated component to determine the degree of true simulation achieved (the investigations included design-point as well as off-design-point performance)

(2) The performance of the reactor simulator when controlled by an analog computer (ref. 2)

(3) Steady-state performance of each loop during long-duration runs

(4) Steady-state performance of the three-loop system during long-duration runs

(5) Variables affecting system startup

(6) Dynamic response of the system to various perturbations in system parameters, for example, primary-loop input power

To obtain the desired data and establish confidence in the final analysis, a large quantity of instrumentation was required. Table I indicates the quantity, type, and range of instrumentation installed for the components and systems. Active sensors as well as spare sensors which were installed as backup units are also listed. In many cases, spare sensors were not installed, because of the physical restrictions of the particular location in the system or where loss of the sensor would not create a critical void in either operation of the system or reduction of data.

Basic Instrumentation Guidelines

To obtain the experimental data desired, basic characteristics of the experiment had to be considered in designing the instrumentation system:

TABLE I. - SNAP-8 INSTRUMENTATION

(a) Temperature measurements

Parameter	Number of thermo-couples	ISA alloy type (a)	Temperature range		Thermocouple outputs[b] to -								
			°F	°K	CADDE	Oscillo-graph	Analog computer	Control-room panel	Profile monitor	Thermocouple		Spare	Alarm
										Average	Miscel-laneous indication		
NaK electric heater:													
Internal and shell	78	K	75 to 1300	300 to 1000	78	---	3	---	---	---	---	---	---
Inlet	3	K	75 to 1130	300 to 900	---	---	---	1	---	---	---	2	---
Outlet	3	K	75 to 1300	300 to 1000	---	---	1	1	---	---	---	2	---
Loop 1 EM pump (inlet, outlet, and coil temperature)	4	K	75 to 1130	300 to 900	2	---	---	2	---	---	---	1	1
Mercury boiler:													
Shell	94	K	75 to 1300	300 to 1000	70	---	---	---	24	---	---	---	---
Inlet (NaK side)	2	K	75 to 1300	300 to 1000	1	---	---	---	---	---	---	1	---
Outlet (NaK side)	2	K	75 to 1300	300 to 1000	1	---	---	---	---	---	---	1	---
Inlet (Hg side)	6	K	75 to 500	300 to 550	3	1	---	1	---	---	---	1	---
Outlet (Hg side)	8	K	75 to 1300	300 to 1000	5	1	---	1	---	---	---	1	2
Mercury vapor cooler	36	J	75 to 360	300 to 450	---	---	---	---	---	2	---	---	---
(including air system)	1	K	75 to 950	300 to 800	1	---	---	---	---	---	---	---	---
Mercury condenser:													
Internal and shell	85	K	75 to 800	300 to 700	62	---	---	---	23	---	---	---	---
Inlet (Hg side)	4	K	75 to 800	300 to 700	1	1	---	1	---	---	---	1	2
Outlet (Hg side)	3	K	75 to 550	300 to 560	1	1	---	1	---	---	---	1	1
Inlet (NaK side)	7	K	75 to 450	300 to 550	4	1	---	1	---	---	---	1	---
Outlet (NaK side)	6	K	75 to 625	300 to 600	6	---	---	---	---	---	---	---	2
Loop 2 mercury pump (inlet and outlet)	4	K	75 to 240	300 to 400	---	---	---	3	---	---	---	1	1

[a]Chromel-Alumel, type K; copper-constantan, type T; iron-constantan, type J; platinum - platinum 13-percent-rhodium, type R.
[b]Number indicates quantity.

TABLE I. - Continued. SNAP-8 INSTRUMENTATION

(a) Concluded. Temperature measurements

Parameter	Number of thermo-couples	ISA alloy type (a)	Temperature range		Thermocouple outputs[b] to -								
			°F	°K	CADDE	Oscillo graph	Analog computer	Control-room panel	Profile monitor	Thermocouple		Spare	Alarm
										Average	Miscel-laneous indication		
NaK to air heat exchanger:													
Inlet, loop 3	3	K	70 to 650	300 to 620	1	1	1	1	---	---	---	---	---
Internal, 1, loop 3	24	K	70 to 650	300 to 620	12	---	---	---	---	---	1	---	---
Internal, 2, loop 3	14	K	70 to 650	300 to 620	2	---	---	---	---	---	1	---	---
Outlet, loop 3	1	K	70 to 450	300 to 550	---	---	1	1	---	---	---	---	2
Air in and out, units 1 and 2, loop 3	84	J	70 to 150	300 to 400	---	---	---	---	---	4	---	---	---
Loop 3 EM pump (inlet, outlet, and coil temperature)	3	K	70 to 450	300 to 550	1	1	---	1	---	---	---	---	1
Loops 1 and 3, NPL[c] EM flowmeter temperature (5 units)	10	K	70 to 300	300 to 425	---	---	---	5	---	---	---	5	---
Venturi temperatures, loops 2 and 3	16	K	70 to 1300	300 to 1000	6	---	---	2	---	---	4	4	---
NPL loop temperatures	10	K	70 to 1000	300 to 920	---	---	---	6	---	---	2	2	---
Heated line temperatures (loops 1, 2, 3, and NPL)	44	K	70 to 1000	300 to 920	---	---	---	---	---	---	12	---	---
Pressure transducer body temperature at diaphragm (19 units)	19	K	70 to 1000	300 to 920	---	---	---	---	---	---	1	---	---
Miscellaneous:													
Cold-trap temperatures (8 units)	8	T	70 to -320	80 to 300	---	---	---	---	---	---	1	---	---
Heater-element temperatures	6	R	70 to 2000	300 to 1350	---	---	---	---	---	---	6	---	---
Low temperatures	18	J	70 to 500	300 to 550	---	---	---	---	---	---	6	3	---
High temperatures	9	K	70 to 800	300 to 700	---	---	---	---	---	---	4	---	---

[a]Chromel-Alumel, type K; copper-constantan, type T; iron-constantan, type J; platinum - platinum 13-percent-rhodium, type R.
[b]Number indicates quantity.
[c]NaK purification loop.

TABLE I. - Continued. SNAP-8 INSTRUMENTATION

(b) Pressure measurements

Parameter	Number of trans-ducers	Trans-ducer (d)	Pressure[e] range		Temperature operating range		Transducer outputs to -					
			psi	N/cm^2	^{o}F	^{o}K	CADDE	Oscillo-graph	Analog computer	Control-room panel	Visual in cell	Alarm panel
NaK electric heater outlet	1	A	0 to 50	0 to 35	1300	1000	✓			✓	✓	
Loop 1 EM pump:												
Inlet	1	A	0 to 50	0 to 35	1130	900	✓			✓	✓	✓
Outlet	1	A	0 to 50	0 to 35	1130	900	✓			✓	✓	✓
Mercury boiler:												
Outlet	1	A	0 to 300	0 to 200	1300	1000	✓	✓		✓	✓	[f]✓
	1	B					✓					
Inlet	1	A	0 to 500	0 to 350	500	550	✓	✓		✓	✓	
	1	B					✓					
Turbine simulator venturi inlet	1	A	0 to 300	0 to 200	1300	1000	✓			✓	✓	
Turbine bypass venturi inlet	1	A	0 to 300	0 to 200	1300	1000	✓			✓	✓	
Mercury condenser:												
Inlet	1	A	0 to 50	0 to 35	800	700	✓	✓		✓	✓	✓
	1	B										
Internal	1	A	0 to 50	0 to 35	800	700	✓	✓		✓	✓	
NaK outlet, loop 3	1	A	0 to 100	0 to 70	625	600	✓			✓	✓	
NaK inlet, loop 3	1	A	0 to 100	0 to 70	450	550	✓			✓	✓	
Mercury pump:												
Inlet	1	A	0 to 50	0 to 35	240	400	✓			✓	✓	✓
	1	B						✓				
Outlet	1	A	0 to 500	0 to 350	240	400	✓	✓		✓	✓	✓
	1	B						✓				
Inlet to NaK to air heat exchanger, loop 3	1	A	0 to 100	0 to 70	650	620	✓			✓	✓	
Loop 3 NaK-to-air heat exchanger unit:												
NaK upper manifold	1	A	0 to 100	0 to 70	650	620	✓			✓	✓	
NaK lower manifold	1	A	0 to 100	0 to 70	450	550	✓			✓	✓	

[d]Slack diaphragm with capillary tube, A; slack bellows, B; strain gage, C; variable reluctance, D: servo, E: direct-reading gage, F.
[e]All pressures are absolute unless otherwise noted.
[f]Both high and low alarm.

TABLE I. - Continued. SNAP-8 INSTRUMENTATION

(b) Concluded. Pressure measurements

Parameter	Number of trans-ducers	Trans-ducer (d)	Pressure[e] range		Temperature operating range		Transducer outputs to -					
			psi	N/cm^2	°F	°K	CADDE	Oscillo-graph	Analog computer	Control-room panel	Visual in cell	Alarm panel
Loop 3 EM pump:												
Inlet	1	A	0 to 100	0 to 70	70 to 450	300 to 550	✓			✓	✓	✓
Outlet	1	A	0 to 100	0 to 70	70 to 450	300 to 550	✓	✓		✓	✓	✓
Mercury condenser ΔP	1	A	[g]0 to 20	[g]0 to 14	70 to 780	300 to 700	✓					
Loop 1 flow venturi ΔP	1	A	[g]0 to 20	[g]0 to 14	70 to 1300	300 to 1000	✓			✓		
Loop 2 flow venturi at boiler inlet	1 1	A F	[g]0 to 20	[g]0 to 14	70 to 280	300 to 410	✓	✓		✓	 ✓	[f]✓✓
Loop 3 flow venturi	1	A	[g]0 to 20	[g]0 to 14	70 to 450	300 to 550	✓			✓		
Mercury condenser:												
Inlet (high frequency)	1	C	0 to 30	0 to 20	70 to 580	300 to 580	✓					
Outlet (high frequency)	1	C	0 to 30	0 to 20	70 to 450	300 to 550	✓					
Mercury vapor cooler inlet	1	B	0 to 400	0 to 275	70 to 1200	300 to 900	✓			✓		
Liquid mercury supply venturis (3) ΔP	3	D	[g]0 to 500	[g]0 to 350	70 to 120	300 to 320	✓			✓		
Mercury condenser exit venturi ΔP	1	D	[g]0 to 10	[g]0 to 7	70 to 250	300 to 400	✓			✓		
Mercury vapor cooler air inlet	1	D	0 to 50	0 to 35	60 to 90	290 to 300	✓			✓		
NaK to air heat exchanger:												
Upstream air	2	D	0 to 50	0 to 35	60 to 90	290 to 300	✓			✓		
Air orifice ΔP	2	D	[g]0 to 30	[g]0 to 20	60 to 90	290 to 300	✓			✓		
Loop 2 mercury vapor venturis	2	D	[g]0 to 200	[g]0 to 140	70 to 250	300 to 400	✓			✓		
Miscellaneous nitrogen and argon gas system pressures	11	E	70 to 3000	0 to 2000	70 to 120	300 to 320				✓		

[d]Slack diaphragm with capillary tube, A; slack bellows, B; strain gage, C; variable reluctance, D; servo, E; direct-reading gage, F.
[e]All pressures are absolute unless otherwise noted.
[f]Both high and low alarm.
[g]Differential pressure.

TABLE I. - Concluded. SNAP-8 INSTRUMENTATION

(c) Miscellaneous measurements

Parameter	Quantity	Range	Outputs[b] to -				
			CADDE	Oscillo-graph	Analog computer	Control-room panel	Alarm
Flow; EM flowmeters, loops 1, 2, 3, and NPL	5	0 to 60 000 lb/hr (0 to 7.5 kg/sec)	√ (4)	√ (3)	√ (1)	√ (5)	√ (6)
Master time clock (recording correlation) 3 channels	1	sec to min	√ (2)	√ (6)			
Valve position indication	8	-----------	√ (4)	√ (2)		√ (4)	
Weight; mercury standpipe and expulsion tank	2	-----------				√	
NaK electric heater input electrical power	1	0 to 650 KW 0 to 65 mV	√ (1)			√ (1)	√ (2)
Analog computer power signal to NaK electric heater	1	0 to 650 KW 0 to 50 mV	√		√ (1)		

(d) Totals

Total measurements			Total outputs								
Temperature (including spares)	Pressure	Miscellaneous	CADDE	Oscillo-graph	Analog computer	Control-room panel	Profile monitor	Thermocouple		Visual pressure in cell	Alarm
								Average	Miscellaneous indication		
642	52	18	302	27	8	67	47	6	38	19	31

[b]Number indicates quantity.

(1) Liquid-metal facilities, to operate reliably, require close adherence to proper procedures in buildup, assembly, cleaning, and operation (ref. 7). Many of the procedures are complex and time consuming. The facility under discussion, by comparison with other liquid-metal facilities in existence, was complex in terms of number of components, number of loops, and operating temperature, pressure, and flow ranges (ref. 8). Since liquid-metal facilities require extensive time to startup, shutdown, and change after the liquid metal is in the system, sufficient instrumentation was installed during the initial buildup to obtain all the information required for all the data goals. With this approach, once operational status of the facility was achieved, all the tests would be completed, barring unscheduled shutdowns, in a minimum amount of time.

(2) The size and complexity of the loops and components, coupled with the detailed performance analysis desired, established the need for a large quantity of measurements to be made (refer to table I).

(3) Test runs generally were to be of long duration and, typically, operation was to be on a 24-hour per day basis.

(4) Environmental conditions for instrumentation sensors were severe. Conditions included long-duration contact with NaK and mercury at temperatures from 70° to 1300° F (300 to 1000° K), corrosive effects from NaK and mercury, and potential fire hazards created by NaK leaks.

(5) A high degree of reliability was required of the instrumentation. The hostile environment and long-duration runs made repair difficult and replacement impossible. Opportunities for calibration checks of sensors were minimum since this could not be done during system operation. External leakage of any of the sensors in contact with the liquid metal could cause a shutdown of the experiment.

(6) Because of the nature of the experiment and the hazards involved, remote control was required along with automatic alarms and shutdown circuits.

(7) Automatic recording of the outputs from a large portion of the sensors was required to reduce analysis time and to ease data taking. Some of the data reduction was to be done by computer.

Specific Instrumentation Guidelines

In addition to the basic guidelines discussed, several specific factors were necessary in planning the overall instrumentation system.

(1) Because of the time schedule for the experiment, commercially available, off-the-shelf, instrumentation equipment had to be used. Insufficient time was available for development of specialized sensors.

(2) A graphic control panel was utilized to control operation of the experiment. It contained visual indications of pressure, temperature, and flow conditions in each loop as well as controls for operating valves, pumps, blowers, etc. Figures 4 and 5 show the size and configuration of the graphic panel.

(3) Total available recording capability was less than the total number of sensors. Therefore, a means of interchanging and selecting measurements to be recorded, for a given test, had to be provided.

(4) More than one recording mode was required to handle all the various types of data. A means of time correlation of each recording mode was required to ensure accurate analysis.

(5) The large quantity of measurements to be made (table I) required a simple positive system of identification and documentation. The system had to be a compact form

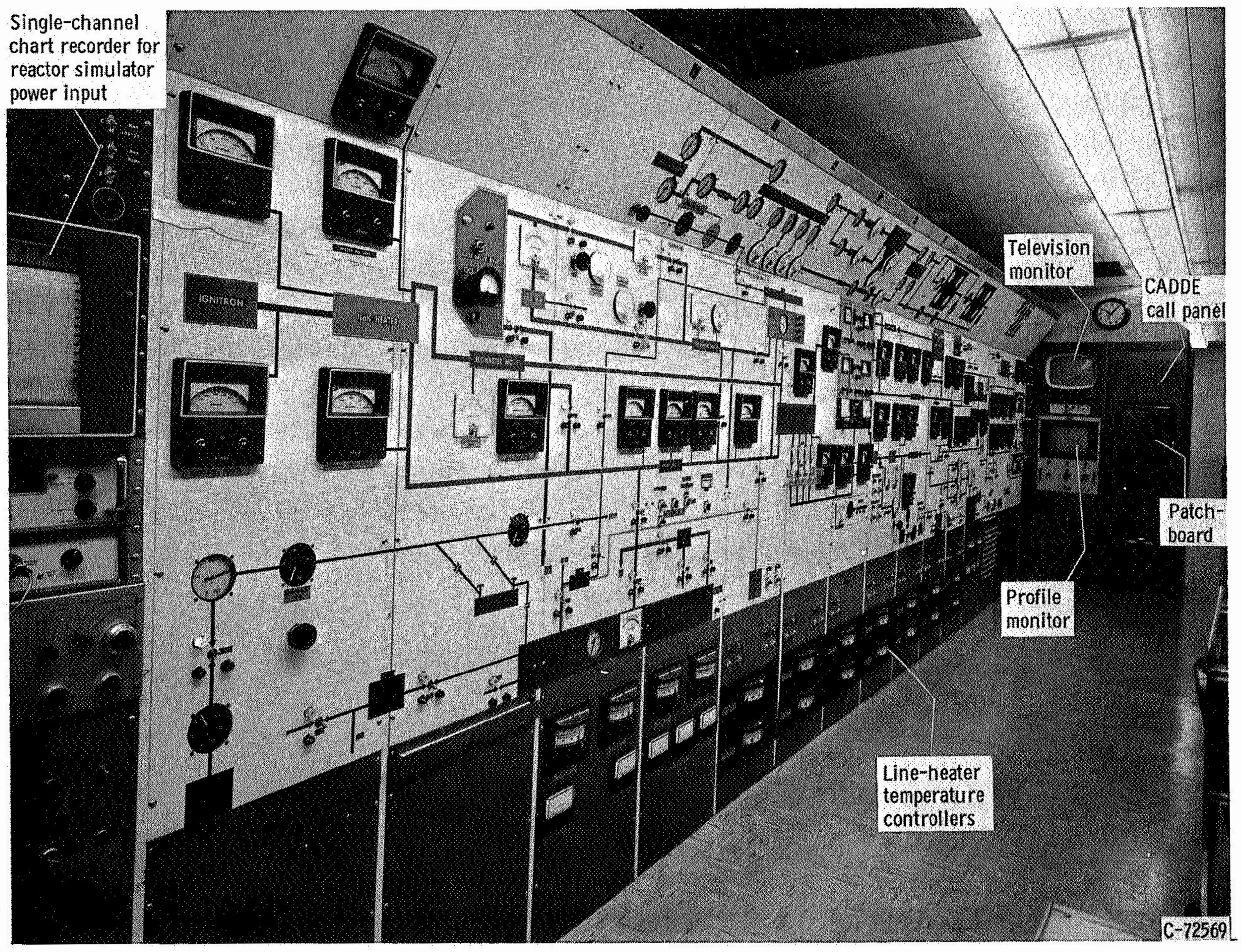


Figure 4. - Control room showing graphic control panel.

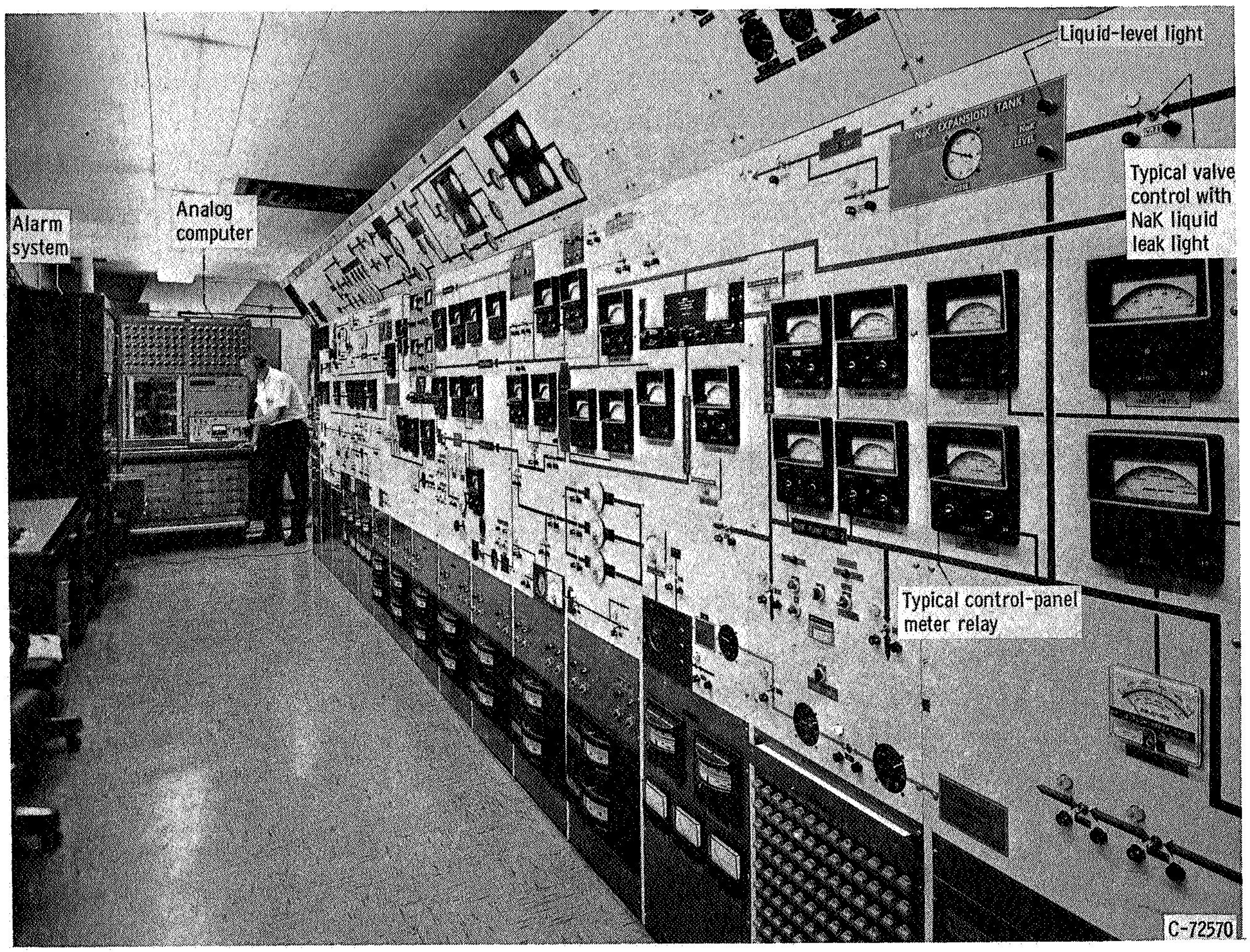


Figure 5. - View of control room showing graphic control panel, alarm system, and analog computer.

and provide all the information required to identify and locate a given parameter in the test cell, trace its signal to the control room, and show how and where it was being utilized.

(6) An instrumentation interconnect system between test enclosure and control room had to be provided which would allow for easy signal tracing and versatility in making changes.

(7) Since approximately 1-megawatt of 60-hertz alternating-current electrical power was to be used throughout the facility, suitable means of shielding low-level instrumentation signals against alternating-current noise was required.

(8) Because of the physical restrictions in some areas of the experiment for installing a sufficient number of sensors, a means of signal-splitting was required to utilize one sensor signal for two or more functions in the control room.

(9) An analog computer was installed to control the operation of the NaK electric heater as the reactor simulator and the NaK-to-air heat exchangers as radiators. These design guidelines provided the foundation from which a suitable instrumentation system was designed and assembled.

SENSOR SELECTION

As stated in the section Specific Instrumentation Guidelines, sensor selection was based on using commercially available units since the timing of the work would not permit development of special sensors. Selection therefore was made by surveying the field of available sensors and choosing those which had features that most nearly met the requirements. If compromises in desired performance were required, the general approach was to lean toward the more reliable rugged sensor and sacrifice fast response and high accuracy.

Temperature Sensors

Thermocouples were chosen as the most practical means of making the temperature measurements required. They were used exclusively except for one specialized application in the reactor simulator, which is discussed later.

Thermocouples fitted the required operating temperature range well (70° to 1300° F (300 to 1000° K)). They were relatively inexpensive considering the quantity required (about 650 including spares). They exhibited good accuracy, reliability, and long life when properly installed and required a minimum amount of support electronics. Equally important was the fact that they required little space and could be attached to almost any surface regardless of its physical constraints.

Chromel-Alumel (ISA type K) thermocouples were used in all three of the liquid-metal loops. Iron-constantan (ISA type J) thermocouples were used for the low-temperature (150° to 200° F (340 to 370° K)) application of the various air lines. Copper-constantan (ISA type T) thermocouples were used to monitor liquid-nitrogen cold-trap temperatures (-200° to -300° F (90 to 145° K)). Platinum - platinum 13-percent-rhodium (ISA type R) thermocouples were used in a few selected locations to monitor electric heating-element sheath temperatures (2000° F (1350° K)). Table I lists the types, ranges, locations, and quantities of each type used.

Each thermocouple was constructed from commercially available stainless-steel sheathed stock of either 0.125- or 0.062-inch (0.318- or 0.159-cm) outside diameter. The alloy conductors within the sheath were oriented parallel to each other and separated by a suitable oxide insulating material.

For temperature measurements within the NaK electric heater, a variation of the standard sheathed stock was obtained. It consisted of a 0.125-inch (0.318-cm) outside-diameter stainless-steel sheath, containing alloy conductors which were spirally twisted loosely about each other with a pitch of 1 to $1\frac{1}{2}$ inches (2.5 to 3.8 cm). A suitable oxide insulating material filled the open space to keep the conductors from shorting together. This construction was used to help reduce alternating-current pickup from the 192 electric heating elements within the simulator.

The thermocouple junction was formed on one end, and the tip was either left open or brazed over, as the application dictated. On the opposite end of the sheath, a two-pin connector, with compatible alloy pins, was installed to an accessible location (2 to 6 in. (5 to 15 cm) in most cases) outside the insulation covering.

Various techniques were used to install thermocouples (fig. 6). Surface, or skin, thermocouples were of the open-tip type. The junction was spot welded to the component surface at the point of measurement after a thermal-expansion loop was formed in the conductors. A small metal strap of stainless steel was welded over the junction to hold it against the component surface in the event of failure of the spot weld between the junction and the component surface. Physical protection of the junction was provided by spot welding a metal cap over the junction where space was available. The sheath was then fixed to the component surface for adequate support of the junction by spot welding metal bands over it. The remaining length of the sheath was then placed through the insulation so that the two-pin connector on the end would be outside the insulation of the component.

Deep wall thermocouples were used in a few locations to reduce the ΔT from the inner surface to the outer surface of the wall of the component. This technique, although more difficult from a fabrication standpoint, had several advantages. In addition to giving a more accurate measurement of fluid temperature at the inner wall surface, the time response of the thermocouple to a change in fluid temperature was reduced. A third advantage was that, since the thermocouple did not completely penetrate the wall,

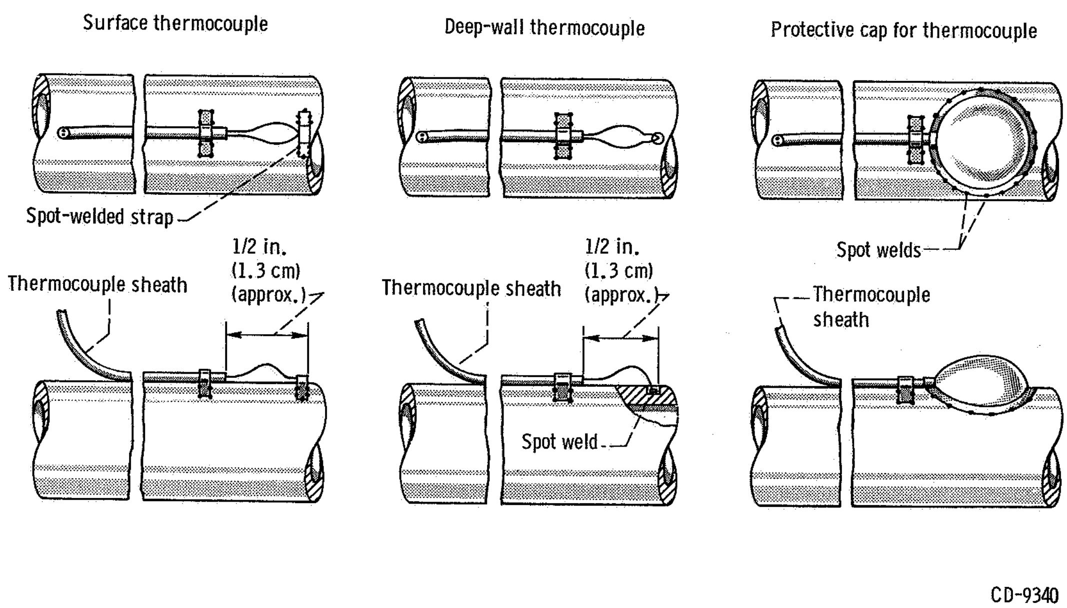


Figure 6. - Typical thermocouple installations (not drawn to scale).

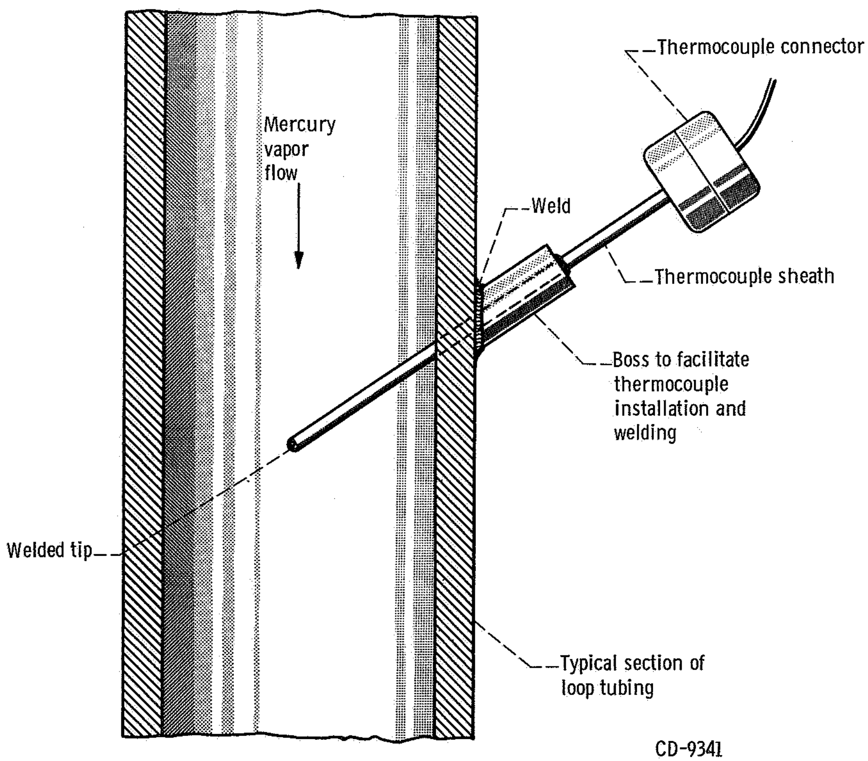


Figure 7. - Installation of typical immersion thermocouple (not drawn to scale).

there was no danger of contaminating the inner surfaces during installation. Also, a failure of the thermocouple junction could not create a path for liquid-metal leakage. For the deep-wall thermocouples, a groove was ground in the wall of the component. The depth of the groove depended on the wall thickness, which varied from about 0.060 to 0.100 inch (0.15 to 0.25 cm). However, in all cases at least 0.030 inch (0.076 cm) of the wall thickness would be left. After the groove was prepared, the junction of an open-tipped thermocouple was spot welded into the bottom of the groove. The groove was then filled with silver braze to restore the wall to its original thickness.

Immersion thermocouples in the liquid-metal piping were used only at the mercury vapor outlet of the boiler. Figure 7 shows the installation technique. These thermocouples were used to give an indication of mercury droplets entrained in vapor when the

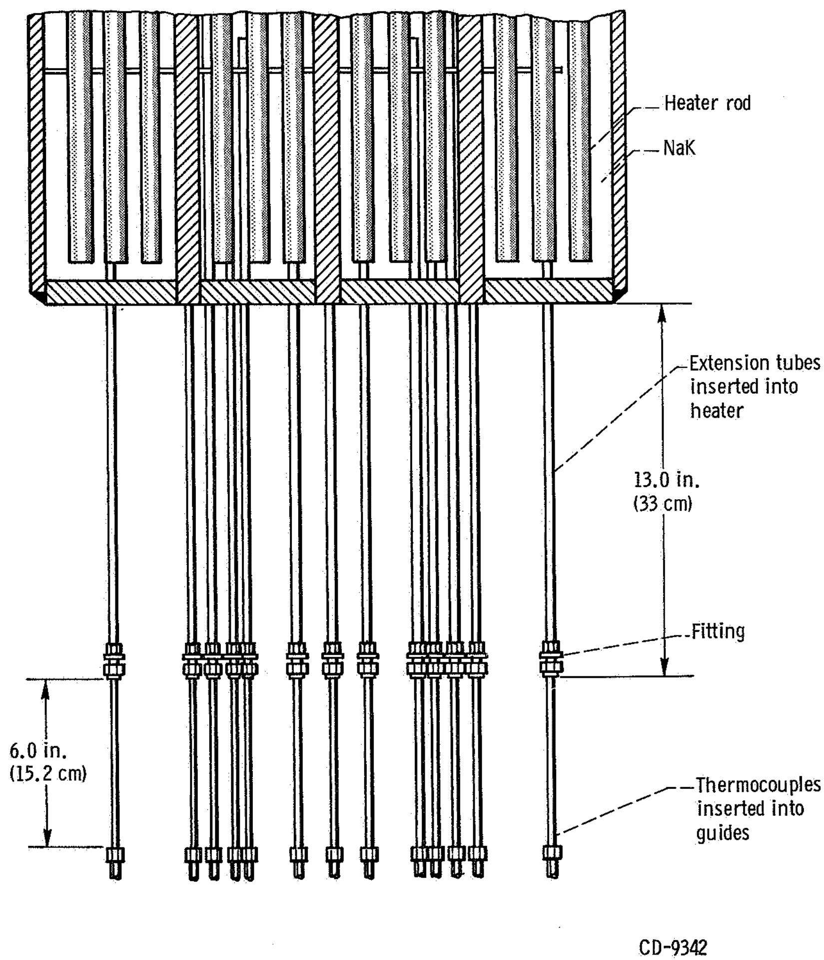


Figure 8. - NaK electric heater internal thermocouple installation.

vapor was superheated by comparing the temperature of the probe facing into the stream with the one facing away from the stream. The lower the quality of the vapor (higher quantity of droplets entrained in the vapor), the greater the difference in temperature between the probes. Liquid droplets in the vapor tend to impact and collect on the probe tip facing into the stream thereby acting as an insulating layer and produce the temperature difference. This layer would cause the probe to indicate a temperature close to the mercury saturation temperature. Mercury droplets tend not to collect on the probe tip facing away from the stream because of the scrubbing action of the vapor flow. Therefore, a better measure of the vapor temperature is obtained from the probe facing downstream. A vapor quality of 100 percent is indicated when both probes measure the same temperature. Measured temperature difference could not be calibrated to give a number to quality since known vapor quality conditions could not be simulated.

Obtaining the performance of a computer controlled electric heater simulating a nuclear reactor was one of the major data goals of the experiment. Therefore, the internal temperature measurements were of primary importance. Fifty-six specially sheathed twisted thermocouples (as described earlier in this section) were installed inside the electric heater and exposed directly to the liquid NaK at 1100° to 1300° F (870° to 1000° K). Replacement of defective thermocouples, together with the design of the simulator, and limited space for installing thermocouples precluded the use of welding as a sealing method.

Figure 8 shows the metal-to-metal NaK seal design that was used. The extension tubes shown were welded to the base plate of the heater at each thermocouple location. A stainless-steel fitting containing two compression sealing ferrules for 0.125-inch-(0.32-cm) diameter tubing was welded to each extension tube. Welded-tip thermocouples were constructed and inserted through the extension tube up to their proper elevation in the heater. The compression ferrule fitting was then tightened to hold the thermocouple in position. The extension tube served to remove the sealing compression fitting from the high temperature of the electric heater shell to a point outside the insulation where the fitting would receive cooling by the test cell atmosphere. The resulting low operating temperature (200° F (370° K) at the fitting) reduced the possibility of it becoming loose and leaking as a result of thermal cycling.

Installation of thermocouples for internal temperature measurements of the mercury condenser was accomplished in a manner similar to that in the reactor simulator. Test conditions were similar except that the temperature level was 600° F (330° K) lower. The need for reliable measurements was just as important since the thermocouples would be measuring the wall temperature variation of one of the mercury condensing tubes to indicate the location of the mercury liquid-vapor interface.

Multiple open-junction thermocouple rakes were used in the inlet air lines of the mercury vapor cooler and the air side of both NaK-to-air heat exchangers. The diameter

of these air lines was such that an average of the air temperature distribution within each line was considered to be more accurate when making heat-balance calculations. Since temperatures would be low, less than 250° F (400° K), iron-constantan was the thermocouple alloy used.

Thermocouple reference ovens. - Figure 3 shows the physical relation of the control room with respect to the test enclosure. When allowance was made for the actual routing of instrumentation wiring, the thermocouples averaged close to 100 feet (30 m) long to the outside of the outer enclosure. The 150° F (340° K) thermocouple reference-junction ovens were selected for use with all the type K, J, and T thermocouples (see table I) and were located adjacent to the test enclosure outer wall. Use of the ovens had two advantages in the overall installation.

(1) Connections from the ovens to the control room were copper. This feature helped maintain reasonably low total circuit resistances without using excessively large thermocouple alloy extensions from the probes to the ovens. Typical total circuit resistances ranged from approximately 10 to 35 ohms when AWG no. 18 alloy extension leads were used.

(2) The oven temperatures were thermostatically controlled and included means of periodically monitoring the reference temperature for drift. This drift after several months of continuous operation was 1° to 3° F (0.5° to 1.7° K) low.

Thermocouple alloy extension cable. - Because of the large amount of 60-hertz alternating-current power throughout the test enclosure, special thermocouple alloy extension cable was used between the thermocouples and reference ovens to minimize alternating-current pickup. The cable consisted of two twisted AWG no. 18 solid alloy leads with polytetrafluorethylene insulation. An overlapping aluminum foil shield was wrapped over the twisted leads and a copper wire. The copper wire was for grounding the cable at any location. A plastic cover was then wrapped over the foil, and a stainless-steel braid applied over the plastic. The final covering consisted of a second plastic wrap over the braid with an outer cover of extruded polytetrafluorethylene. The final cable was 3/16 inch (0.48 cm) in diameter, and in addition to providing shielding against alternating-current noise, it could withstand temperatures to 375° F (470° K). Approximately 22 000 feet (6700 m) of this cable were used in the facility.

Thermocouple patchboard. - A patchboard (fig. 3) was used between the output of the thermocouple reference ovens and the copper interconnect cables to the control room. This patchboard provided a means of selecting those thermocouples that needed to appear on the control-room patchboard for a given test without rewiring interconnections. Because of the volume of instrumentation and necessary associated space, the control-room patchboard could not accommodate all the thermocouples at any one time.

Reactor simulator averaging temperature sensor. - In addition to the thermocouples installed internally in the reactor simulator, three specially developed bimetallic tem-

perature sensors (ref. 9) were installed to indicate the average temperatures of three selected heater elements. The sensors were designed to fit in a small slot cut into the side of the heater element for its entire length. The sensor operated on the principle of thermal expansion of dissimilar metals. The amount of thermal expansion was a function of the average temperature. Resulting displacement of the metal rods with respect to the heater was converted to an electrical signal by an LVDT (linear variable differential transformer).

Pressure Sensors

Table I lists the locations, types, ranges, and quantities of pressure sensors used in the facility. Figure 1 shows the general environmental liquid-metal conditions which the pressure sensors had to withstand. In addition, pressure sensors were also required for the secondary gas systems where the ambient temperature was 250° F (400° K) or less. The following factors were considered in selecting the pressure measuring units used:

(1) The unit had to be in the form of a transducer providing a suitable electrical output signal proportional to pressure.

(2) The sensor portion of the transducer had to be fully compatible with NaK and mercury and withstand temperatures ranging from 70° to 1300° F (300° to 1000° K).

(3) The unit had to be commercially available.

(4) The unit had to be suitable for welded installations and be relatively easy to handle without damage.

(5) The unit design had to allow for close coupling of the sensor to the process line to reduce the chance of plugging in NaK lines and to improve frequency response.

(6) The unit had to exhibit long-term calibration stability with respect to time and temperature.

(7) The unit had to be designed so that a failure of the pressure sensing element would not cause a leak of the process fluid.

(8) The unit had to have a good frequency response (40 to 50 Hz desired) while maintaining high reliability.

(9) The unit had to provide reasonable accuracy (1 percent or better).

(10) For primary pressure measurements, the unit had to provide a means of direct visual indication of pressure as well as an electrical output for data recording.

These factors applied primarily to the liquid-metal loops. Transducers required for measurements in the secondary gas systems did not have to meet the temperature and liquid-metal compatibility requirements.

Based on these considerations, the following types of transducers were selected:

Slack diaphragm with capillary tube. - This unit was used for the absolute (psia (N/cm^2 abs)) liquid-metal pressure measurements at temperatures to 1300° F (1000° K) where fast response was not required. It consisted of a stainless-steel process attachment tube and diaphragm housing. The diaphragm in the housing was a slack diaphragm and served to separate the process medium from NaK in the capillary tube which transmitted the applied pressure to a Bourdon tube in a remote case. Through suitable linkages, the movement of the Bourdon tube was simultaneously displayed on a visual scale and converted to a constant current (1 to 5 mA) electrical signal by using an LVDT and signal conditioner. Frequency response of these units was limited to 1 hertz or less by the 10-foot (3 m) capillary tube.

For liquid-metal differential pressure measurements requiring an electrical output, a variation of the slack diaphragm unit was used. The diaphragms, housings, and capillary tubes were similar to the absolute units. Within the housing, an air-operated force-balance system furnished an air output of 3 to 15 psi (2 to 10 N/cm^2) proportional to the pressure difference. The air-output signal was used to drive a 50-kilohm potentiometer in a second and more remote unit to provide the electrical output signal.

Slack bellows units. - Because of their higher frequency response, these units were used in the mercury loop to provide supplementary information on loop dynamics. A slack bellows and housing capable of withstanding 1300° F (980° K) received the process fluid and pressure. A force rod transmitted the pressure to force-balancing springs. The force rod passed through a finned area of the housing from which heat was radiated to lower the temperature in the force balance spring and LVDT areas of the transducer. Passing through the force-balancing springs, the rod extended into the LVDT area where the LVDT core was attached to the end of the rod. Movement of the force rod was thus converted to a 0- to 1-milliampere electrical signal by the LVDT and associated signal conditioner.

High- and low-temperature strain gage. - The high-temperature units could operate in environments up to 650° F (620° K) and were used in the mercury loop on the mercury condenser for supplemental information. They were of an all-welded stainless-steel design with the entire transducer including electrical connector being capable of withstanding the maximum operating temperature.

The low-temperature units could withstand 250° F (400° K) and were not an all-welded design. These transducers were used in the air, nitrogen, and argon systems. The output signal of these units was approximately 3 to 4 millivolts per volt.

Variable reluctance transducer. - These units, capable of operation to 250° F (390° K), were used in miscellaneous applications such as air lines, mercury injection system, mercury boiler outlet, mercury venturis, etc. A signal conditioner with each unit provided an electrical output of 0 to 5 volts direct current.

Servotransducer. - Suitable for low-temperature applications, these units were used to display pressures in the nitrogen, argon, and air systems on the control panel. Power requirements were 28 volts and 400 hertz. No electrical output signal for recording was provided.

Direct-reading gage. - As a backup gage, a direct-reading differential-pressure gage was used on the mercury liquid venturi. During operation, this gage was observed by use of the television monitor.

To ensure successful operation and accurate data from the pressure transducers, a number of installation techniques and precautions were followed. On all the horizontal liquid-metal lines, transducers were installed vertically above the line. This provided good drainage in the NaK lines and minimized the possiblity of plugging due to oxide precipitation. Transducer to process line attachment tubes were kept as short as possible to maintain good frequency response. All joints were welded, and each transducer standoff length to the process line was measured so that head correction factors could be calculated. Insulation around process lines was extended up around the transducer attachment tube to maintain working temperatures. In addition to insulation, electric heaters were used on the standoff tubes of the mercury vapor transducers to maintain vapor in the transducer. Transducer installation on gas lines followed conventional low-temperature practices of using metal-to-metal flared fittings on attachment tubes.

Flow Sensors

Table I indicates the flow measurements that were required in the facility. For NaK flow measurement, both EM flowmeters and a venturi were used. Both types were used because of their compatibility with liquid metals, reasonable reliability over long time periods, and availability. The venturi installed in the heat-rejection loop served as a backup for the EM flowmeters. The flow rate was calibrated as a function of pressure drop. Both types were installed by using welded joints. The body temperature of the EM flowmeters was measured to provide temperature corrections for the volumetric flow.

Liquid-Level Sensors

Liquid-level sensors were required for measurements in the following tanks: NaK expansion and dump tanks, and mercury expulsion and standpipe tanks. The methods selected were determined by the following factors:

(1) The need for analog indication against step indication

(2) Tank physical shape, operating temperature, and pressure

(3) Liquids involved

For the step indications, insulated probes were constructed and inserted through the top of each tank to the desired level. Three probes were used in each NaK expansion tank and one probe in the NaK dump tank. Indication in the control room was obtained by connecting a light and power source in series with each insulated probe and the tank wall. The liquid metal in the tank then acted as a switch completing the circuit between the tank wall and the tip of the probe as the level increased, or breaking the circuit as the level decreased below the probe tip.

The analog indications for the mercury expulsion tank and mercury standpipe tank were obtained by weighing the tanks with strain-gage-type load cells. This simple approach was suitable because the dead weight of the tanks was small in relation to the total weight change caused by the mercury. Good resolution of mercury weight was therefore obtained. In addition, the installation of the tanks in the system was designed so that connecting lines had little affect on the weighing system.

Position Sensors

Flow rates in the three liquid-metal loops and in the auxiliary systems were controlled by valves. The position of the stem of these valves was controlled by a nitrogen gas pressurized operator on the valve, which could be varied from the control room. In order to set up or repeat specific test conditions, the position of the valve stem had to be known accurately.

Two methods were adopted for monitoring valve stem position. For those valves in which the stem position had to be known within 0.010 inch (0.025 cm), commercial linear potentiometers were used. The potentiometers were mechanically connected directly to the valve stem. Electrically, the potentiometers were connected through a power supply to a meter on the control panel in the control room adjacent to the controller for the valve. In some locations, such as the auxiliary systems, the valve stem position was not critical but did require monitoring. For these applications, a pressure transducer was connected to the valve operator to monitor applied nitrogen gas pressure. The resulting transducer signal was then displayed on a meter in the control room adjacent to the valve controller. The accuracy of this method was less than the potentiometer method primarily because system pressures could have an effect on valve stem position thus requiring a different operator pressure to obtain a given stem position.

Total valve stroke for all the valves was approximately 1/2 to 1 inch (1.25 to 2.5 cm).

Oxygen Sensor

A nitrogen inerting system was employed in the test enclosure to reduce the possibility of fire and smoke in the event of a NaK leak. To ensure that the nitrogen inerting system was working properly and the oxygen content was within the limits established, a continuous oxygen monitoring system was used. In addition to monitoring the test enclosures, the atmosphere outside the test enclosure entrances was continuously checked where nitrogen leakage could cause an oxygen depletion and create a hazard for personnel working in the area. The system operated continuously and provided a permanent record of the oxygen levels.

The monitoring system consisted of a commercial dual-range thermo-magnetic oxygen analyzer which used the paramagnetic properties of oxygen to measure its volumetric content. This was coupled to an eight-station sampling system and two-pen strip-chart recorder. Figure 3 shows the location of the analyzer. The 0- to 10-percent range of the analyzer was connected to six sampling stations inside the test enclosure while the 0- to 25-percent range was used for two stations outside the test enclosure. Acceptable oxygen limits were 3 percent maximum within the test enclosure and 16 percent minimum outside the test enclosure. A vacuum pumping system provided a continuous supply of gas from each sampling station to be analyzed. An automatic stepping circuit controlled solenoid valves which admitted, in rotation, the sample from each station to the analyzer. The proper range of the analyzer was also selected by the stepping circuit for the station being sampled. Two minutes were allowed for the analysis. During the analysis, one pen of the strip-chart recorder recorded the oxygen content in percent by volume, while the second pen indicated the station being sampled.

Mercury Vapor Sensor

Because of the toxic effects of mercury vapor, a means had to be incorporated to detect it. The system selected continuously monitored the test enclosure and provided an alarm in the control room. A commercial mercury vapor detector system with eight sampling stations was used. The sampling stations were located in the test enclosure, across all air-cooled heat exchangers, and on the roof of the test enclosure and building. The detector sequentially sampled each station. If mercury vapor were detected, an audible alarm would sound and a light would indicate the station being analyzed. Because of the size of the unit and distance limitations between the detector and sampling stations, the system was installed near the test enclosure. Operator indication was provided by paralleling the sampling station lights and audible alarm in the control room.

RECORDING TECHNIQUES

The general and specific instrumentation considerations for the facility applied also to the recording system. The complexity of the facility and detailed analysis desired required a large number of measurements to be made and consequently a recording system large enough to record these measurements. Automatic recording of much of the data was required in a form suitable for later computer computation. Commercially available equipment had to be utilized to meet schedules. More than one recording mode was required with a means of time correlation between the various modes. The following recording techniques were used.

CADDE

CADDE (Central Automatic Digital Data Encoder) reported in reference 10 is a digital sampling and central data recording system in use at Lewis. The digital recording portion of this system was housed in a building with all of the Center's digital computing equipment and connected to remote relay stations by telephone cables. Several test facilities used the same relay station and were connected into the relay station through a patchboard. The relay station for the SNAP-8 test facility could handle 400 data channels at signal levels to 50 millivolts. Function of the relay station was to digitize each channel signal sequentially and transmit it to the central recording area. Sequencing was accomplished by a crystal controlled signal from the main recording station which activated individual channel relays at the relay station. Recording rate was 20 words (channels) per second; 350 channels were scanned so that a given channel was recorded every $17\frac{1}{2}$ seconds. Channels to be recorded were consecutively arranged in the patchboard from the first to the last channel. Thus, if 20 channels were to be recorded, the last channel number (20) would be preset and sampling would be at the rate of once every second.

The digitized signal received by the central recording station was arranged in the proper format with identification and then recorded on magnetic tape. Immediately following the data run, any or all the channels recorded for a given data run could be sent back to the test-facility control room and typed on a special typewriter. After the data run and other identification, the channel signal and identification were typed as an eight-number word, ten words per line. The last four numbers of the word as counts represented the data signal in increments of 1/1000 of 50 millivolts, that is, a 25-millivolt signal would be seen as 500.0 counts. The maximum number of counts recordable was 999.9. This information was then converted into useful engineering values by control-room personnel from calibration curves of the individual instrumentation.

The CADDE system was selected as the primary data-recording mechanism since a new system of equivalent capacity would have been costly to purchase. CADDE was a proven available system and provided computer compatibility for the data. Only four test facilities at any given time could be handled by the recording system. Since there were various relay stations from many test facilities, use of the recording system had to be scheduled. Problems of having to wait to record a data run and the impracticability of long-duration data runs did not outweigh the advantage of using this existing data-recording system.

Light-Beam Recorders (Oscillograph)

As a secondary recording system, three commercial 24-channel light-beam oscillographs were used. These units could provide a continuous record of a parameter and did not present any scheduling problems with other experiments as did CADDE. Dynamic phenomena in which changes occurred up to 3 to 4 kilohertz could easily be recorded by the proper selection of galvanometer and chart speed. Recorder input level requirements were compatible with the signals to be recorded so that in most cases only passive signal conditioning such as the resistor network shown in figure 9 were required. These units were used primarily for studying unusual transients that could occur during system operation, such as pressures, flows, and certain temperatures.

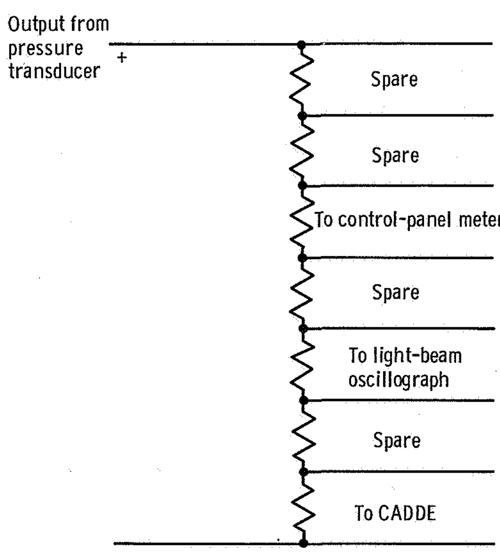


Figure 9. - Passive resistor network for slack-diaphragm - capillary-tube and slack-bellows transducers.

Analog Computer

An analog computer was incorporated into the system to provide two important optional "on-line" control simulations individually or simultaneously. First, the computer coupled with the electric heater simulated the operation of the nuclear reactor that could be used in the final SNAP-8 flight system. Second, the computer could provide control signals to the NaK-to-air heat exchanger to make it operate like a space radiator. The computer contained 40 trunk lines which could be used either for inputs or outputs. Computation functions included 5 multipliers, 28 summers, and 20 combination integrator-summers. In addition, several special reactor simulator control and safety circuits were incorporated into the computer as well as a six-channel chart recorder. Table I lists some of the temperature and flow parameters which were inputs to the computer. A more detailed description of the computer function is presented in reference 2.

Strip-Chart Recorders

Three commercially available strip-chart recorders were employed to provide slow speed continuous records of some parameters during long runs. These units were selected because of their large easy-to-read charts and reliability over long periods. One single-channel unit was used to record reactor simulator input electrical power. A second, two-channel unit was used in the oxide control system to indicate plugging valve flow and temperature. The third recorder, a two-channel unit, was used to record test enclosure oxygen content during test facility inerting with nitrogen as well as the number of the oxygen sensors being sampled.

Multipoint Strip-Chart Recorder

Two 24-point strip-chart recorders were chosen to provide supplementary recording of temperatures during operation. They also helped reduce manual monitoring of hourly check items. Chart speeds were selected to be as slow as possible without having printed indications for adjacent channels obscuring each other.

Signal Transmission, Conditioning, and Switching

The signal transmission, conditioning, and switching system design provided a means of quickly switching between various recording modes. A single sensor output signal was

generally split or switched for each recording mode. As the test program changed, recording requirements would change and thus sensor outputs could be switched quickly and easily.

Signal Transmission

Signals were divided into two categories for transmission from the test enclosure to the control room. All thermocouple signals comprised one group, while pressure transducers, flowmeters, and position transmitters formed the second group. Figure 3 shows the location of the terminal boxes for the transmission system. Thermocouples from the test enclosure connect to the inputs of the thermocouple reference ovens, H. The outputs of the reference ovens, H, terminate as inputs in the thermocouple patchboard, F. From the output side of the patchboard, F, thirteen 50-pair double-shielded transmission cables pass through junction box, G, and terminate in the control room at junction box, C. All transmission wires from the output of the thermocouple reference ovens to the box, C, are copper. Pressure-transducer, flowmeter, and position-transmitter leads from the test enclosure terminated in the junction box, N. From the box, N, shielded copper transmission cables were routed to the box, C, in the control room. Terminal strips were used as the means of terminating all cables in each junction box. They provided quick reliable connections and served as convenient points for trouble shooting individual circuits. All instrumentation leads, including thermocouple extension leads, were shielded to provide maximum freedom from alternating-current noise pickup. All power wiring was routed separately from the instrumentation wiring to minimize the chance of alternating-current noise pickup in the instrumentation wiring.

Signal Conditioning

Because of the variety of electrical outputs from the sensors used, a signal-conditioning system was required to convert each sensor output signal into millivolts suitable for recording on the CADDE system. The system was also flexible to allow for rapid changing of recording parameters as test requirements changed. The ± 50-millivolt full-scale input range on CADDE was chosen as the standard. Two basic methods of conditioning signals to this level were used, namely, passive resistor networks and differential variable-gain amplifiers.

Passive resistor networks were used for the slack-diaphragm - capillary-tube and slack-bellows pressure transducers. Figure 9 schematically illustrates the operation of

these networks. The networks also acted as signal dividers and provided a convenient means of driving a panel meter when required.

The differential variable-gain amplifiers were used both to divide sensor output signals and to amplify signals when required. Gains ranged from 1 to 1000, variable, with a differential input impedence of 10 megohms or greater. These units were used for amplifying strain-gage transducer outputs and dividing various other outputs as required. Sixty-four of these units were installed.

Thermocouple and flowmeter millivolt outputs in general were used in their raw form and not conditioned up to the full-scale 50-millivolt level for CADDE because of the large number involved. An exception to this rule involved two conditioning systems for averaging certain thermocouple outputs. The first system, an NASA design, was used to obtain averaged outputs of iron-constantan thermocouples installed on rakes in the NaK-to-air heat exchanger and mercury vapor cooler air lines. The temperature rakes involved are listed in table I. The system provided a manual means of selecting the thermocouples to be averaged. First, each thermocouple output was scanned on a temperature indicator through a rotary switch. A toggle switch for each thermocouple, on the averaging unit, was positioned either to include or exclude the thermocouple from the average. After the scanning and selection operation, the scanning switch was turned off and the averager output switch was turned on to obtain the average temperature. The average was obtained by paralleling the outputs of the thermocouples selected to make up the average. Each averager had a maximum input capacity of 30 thermocouples.

The second thermocouple averaging system was a commercial unit used to average certain thermocouples in and around the reactor simulator. The unit contained 18 averaging channels each of which would accept three thermocouples to be averaged. In operation, the signals from the three thermocouples of a given channel were compared with each other. The two signals nearest the same level were averaged and the resulting signal became the output for that channel. The third thermocouple signal was disregarded. If one of the three thermocouples was defective it was indicated by a fault light. In addition, the two thermocouples making up the average were indicated by lights. After the averaged signal had been obtained, the unit stepped to the next channel and the averaging process was repeated while the former channel held the average obtained. The unit continuously stepped through each channel so that the averaged output from each channel was updated approximately every 25 seconds. An additional feature of the unit was the ability to give an averaged signal for a group of three channels. Thus, a single averaged output signal could be obtained for nine thermocouples. Two such groups of three channels each were available in the unit.

TABLE II. - INPUTS AND OUTPUTS ON

CONTROL-ROOM PATCHBOARD

Quantity	Inputs to patchboard
288	Thermocouples
5	Type B pressure transducers
2	Type C pressure transducers
13	Type D pressure transducers
4	EM flowmeters
12	Thermocouple averaged signals
6	Thermocouple averaged signals (NASA)
22	Type A pressure transducers
64	Differential amplifiers
24	Analog computer trunk lines
Quantity	**Outputs from patchboard**
64	Differential amplifiers
72	Light-beam oscillograph channels
350	CADDE channels

Signal Switching

One of the basic considerations for the signal-conditioning system was the ability to interchange recording parameters quickly as test requirements changed through the use of a 3264-point commercial patchboard in the control room. The unit can be seen in the far corner of the control room in figure 4. Table II lists the quantity and variety of inputs and outputs that were available on the patchboard. Connection of one point on the board with another was made by using a plug-in patchcord. Therefore, changes could be made by simply changing the patchcord. Even this operation could be time consuming when the large number of points was considered. The patchboard panel was constructed as an assembly of a frame containing the contacts to which all input and output wires were connected and a removable patchboard into which the patchcords were inserted. Thus, changeover time for a new test was reduced by utilizing a spare patchboard and patchcords as a subassembly to wire the desired instrumentation before the test began. There is only space for 288 thermocouples on the patchboard. If a test should call for a thermocouple to appear on the patchboard which was not among the 288 already on the board, the required thermocouple could take the place of an existing one by interchanging patchcords at the thermocouple patchboard, F, near the reference ovens shown in figure 3. Hard wire switching for all parameters is provided at the terminal strips in the junction box, C.

Patching, signal tracing, and wiring information for all parameters is shown on the Parameter Recording Chart, a sample page of which is shown in table III. Reading from left to right, the identifying number of the parameter in the test enclosure is first given with a description of the measurement. Then, each intermediate termination point and wire number between the test enclosure and the junction box, C, in the control room is listed. Control-room termination, signal conditioning, readout, alarm, patchboard, and recording information is then provided. Thus, this single document provided all necessary information for each parameter. The recording columns needed only to be modified to establish the requirements for each new test series.

TABLE III. - TYPICAL PAGE OF PARAMETER RECORDING CHART

Item	Location	Thermo-couple reference oven channel	Cell patch-board input	Cell patch-board output	Cell junction box terminal strip number	Cable number	Control-room terminal strip number (C box)	Thermo-couple averager channel	Panel meter	Alarm system channel	Control-room patch-board input	Ampli-fier number	CADDE channel	Ampli-fier number	Visi-corder channel	Ampli-fier number	Analog com-puter channel	Scanner channel	Remarks
151	Mercury vapor cooler outlet (2-8)	PB4-11	19-WX	58-JK	17C-6	6-31	27A7				11UV		151						
152	Mercury condenser - NaK inlet skin temperature (3-16)	PB5-1	1-AA BB	53-NP	13C-23	5-23	34A7				5AA BB		273						
153		-2	-CC DD	-QR	-24	-24	8				5CC DD								
154		-3	-EE FF	-ST	-25	-25	9		Meter relay		5EE FF				B5				
155		-4	-GG HH	-UV	-26	-26	10		29										
156	Mercury condenser outlet skin (2-12)	-5	-JJ KK	58-UV	17C-11	6-36	27A12				12AB		170	21	A11				
157		-6	-LL MM	-WX	-12	-37	28A1		Meter relay		12CD								
158		-7	-NN PP	-YZ	-13	-38	2		25	25									
159	Mercury pump venturi (2-18)	-8	-QQ RR	59-AB	-14	-39	3				12EF		177						
160	Mercury pump venturi (2-18)	-9	-SS TT	-CD	-15	-40	4				12GH								
161	Mercury condenser; wall skin temperature profile, location Y (3-18)	-10	-UU VV	-EF	-16	-41	5		Pro-file moni-tor 1		12JK								

163	Mercury condenser; wall skin temperature profile, location Y (3-18)	-11	-WW XX	-GH	-17	-42	6		3		12LM								
165		-12	-YY ZZ	-JK	-18	-43	7		5		12NP								
167		-13	2-AA BB	-LM	-19	-44	8		7		12QR								
169		-14	-CC DD	-NP	-20	-45	9		9		12ST								
171		-15	-EE FF	-QR	-21	-46	10		11		12UV								
173		-16	-GG HH	-ST	-22	-47	11		13		12WX								
175		-17	-JJ KK	-UV	-23	-48	12		15		12YZ								
177		-18	-LL MM	-WX	-24	-49	29A1		17		1AA BB								
162		-19	-NN PP	-YZ	17C-25	6-50	2		2		1CC DD								
164		-20	-QQ RR	60-AB	19C-1	7-1	3		4		1EE FF								
166		-21	-SS TT	-CD	-2	-2	4		6		1GG HH								
168		-22	-UU VV	-EF	-3	-3	5		8		1JJ KK								
170		-23	-WW XX	-GH	-4	-4	6		10		1LL MM								
172		-24	-YY ZZ	-JK	-5	-5	7		12		1NN PP								

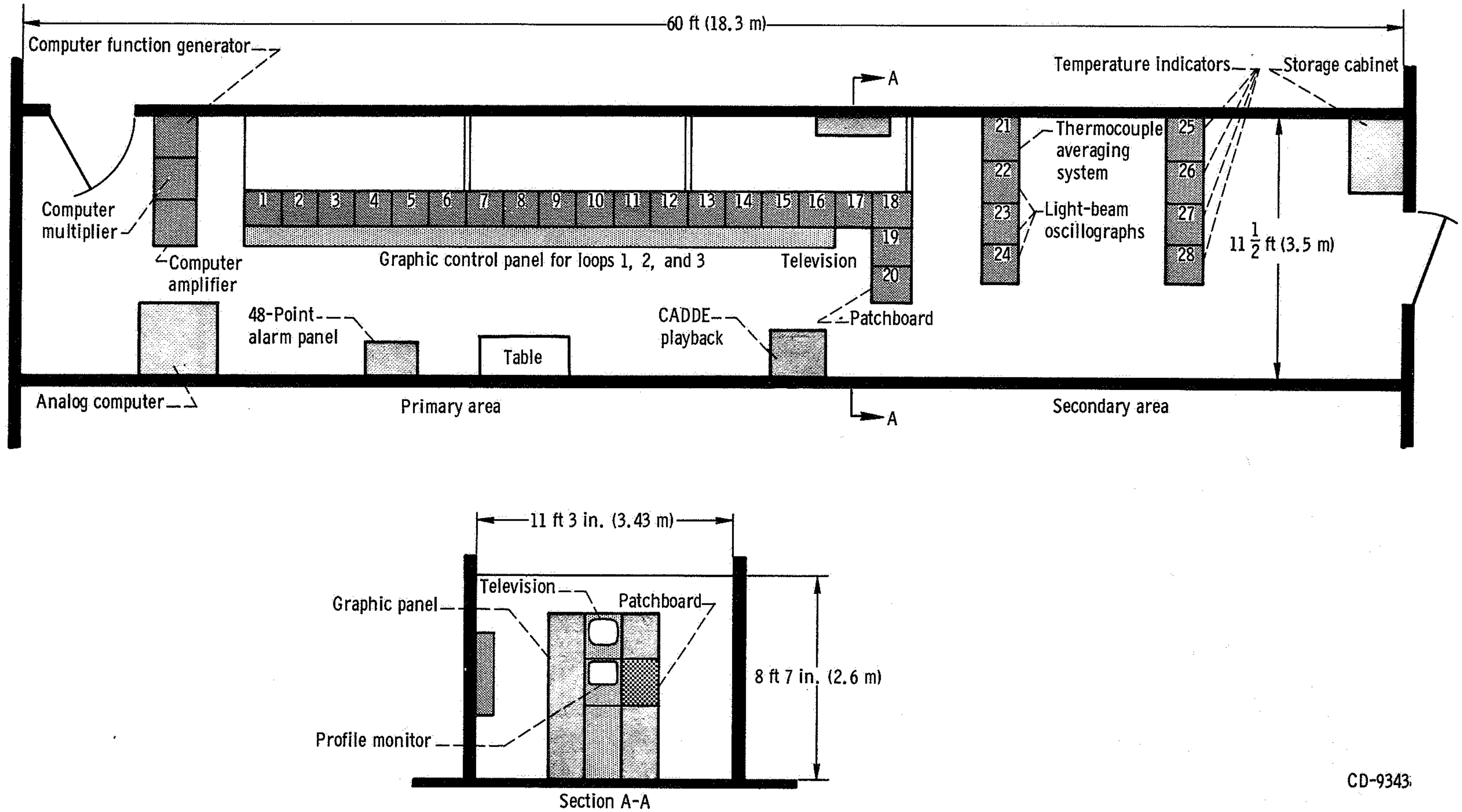


Figure 10. - Plan view of SNAP-8 control room.

CONTROL ROOM

Two of the design guidelines discussed previously applied to the control room. Item (6) in the section Basic Instrumentation Guidelines established the need for remote control of the experiment due to the hazards involved, coupled with automatic alarms and shutdown circuits to aid the operators of the experiment. Item (2) in the section Specific Instrumentation Guidelines set forth the requirement that a graphic panel had to be installed to help the operators visualize the test loops and control them.

The size and shape of the control room (figs. 3 and 10) although not considered to be either the ideal size or shape had to be used for the facility. The room was divided into two general areas: a primary area containing all controls and visual indicators needed for operation, and the secondary area required for equipment that did not need to be monitored for operation of the facility.

Primary Operating Area

Graphic panel and controls. - The largest item in the primary operating area was the graphic control panel shown in figures 4, 5, and 10. The control panel was arranged to represent schematically the physical arrangement of the piping in the actual loops as near as possible. Colored tape was used to represent the piping with the various colors indicating the fluid or gas being carried in the pipe. Components and control valves in each loop were represented by appropriate labels and decals. Meters required for monitoring pressure, temperature, flow, etc., were located on the panel as near as possible to the actual point of measurement. Controls for valves were at the actual locations with valve controls and pipes on the panel sufficiently spaced to minimize the chance of error during operation.

The visual indicating meters on the panel were of two general types. Meters giving a visual indication only were used in noncritical measurements. Meter-relay combinations with adjustable high and low set points were used for the critical parameters where an off-normal indication could cause trouble if it went unnoticed. Closing the relay contacts set off an audible and visual alarm or would in certain cases trigger an automatic shutdown of the experiment. Ranges and units of all meter scales were matched to the measurements being made so that no interpretation of the meter indication was necessary to understand the actual reading. Pressure and flowmeter inputs were matched to their respective transducers. The temperature meters used did not need cold-junction compensation since they were used directly with the thermocouple reference ovens outside the test enclosure. The meters had internal thermocouple break protection as well as the ability to operate with external thermocouple circuit resistances of 30 to 60 ohms, depending on the temperature range.

Valve controllers consisted of a common aircraft quality double-pole-double-throw

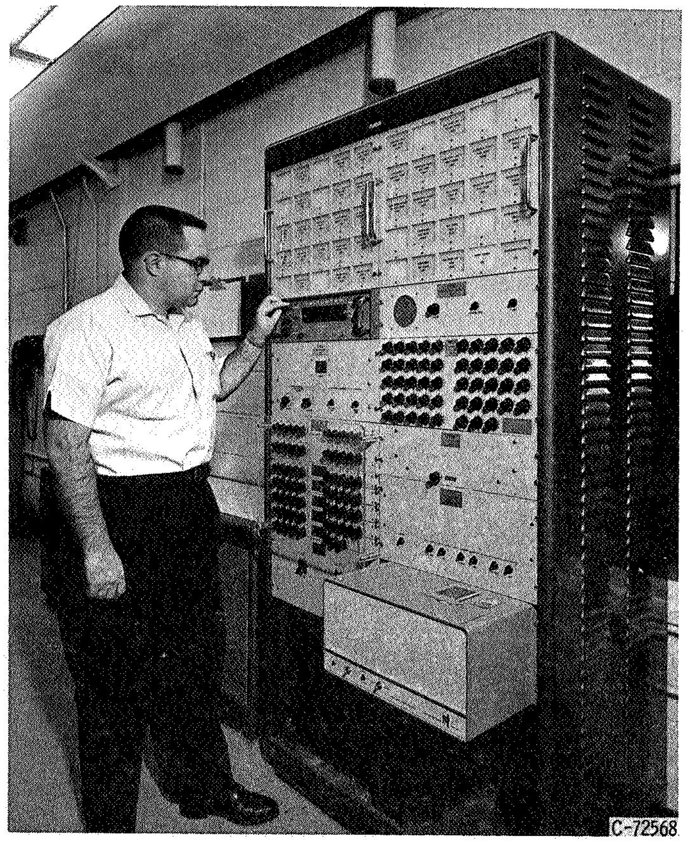


Figure 11. - Automatic alarm system.

toggle switch used with either two or three indicating lights for visual position confirmation. In operation, the toggle switch controlled a solenoid valve which in turn controlled nitrogen gas pressure to the operator of the valve. Toggle switches were chosen for two reasons. First, they were inexpensive, physically small, positive in action, and reliable. Second, and most important, in the event of an indicator light failure or general power failure, the position of the valve was easily determined from the position of the toggle switch bat at the time of the failure. The switches were installed and wired so that the UP position of the switch bat indicated valve open and the DOWN position indicated valve closed. This rule was observed regardless of whether the schematic line and valve symbol on the panel passed horizontally or vertically through the switch.

Alarm system. - Because of the complexity of the experiment, an automatic alarm system (fig. 11) was needed to give visual and audible indication of off-normal occurrences. A commercially available system with a capacity of 48 channels was selected. Operation required only an external contact closure which in most cases was obtained from the meter relays on the main control panel. On closure of any channel external contact, an audible tone would emit from a speaker on the unit and, at the same time, a red light would flash in the window of the alarmed channel. Pressing the acknowledge

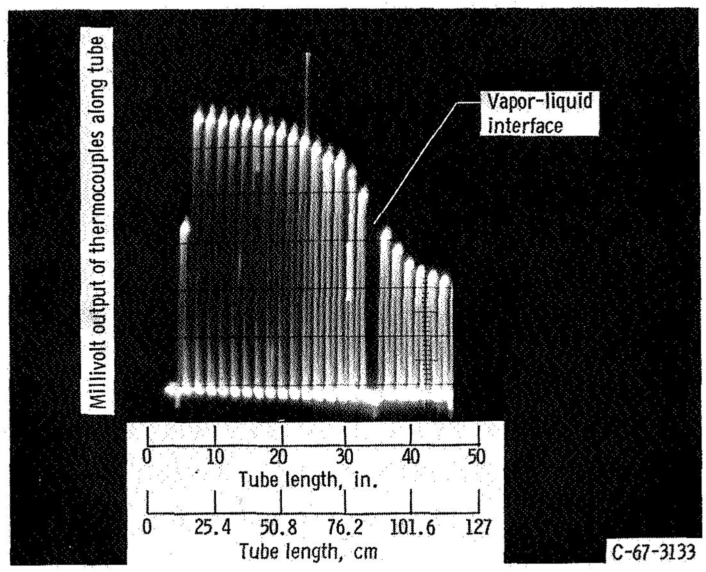


Figure 12. - Typical condenser temperature profile obtained on profile monitor.

switch on the unit stopped the audible alarm and changed the flashing red light to a steady white light which remained lighted until the off-normal condition was corrected. A test switch on the unit provided a means of operationally checking all channels simultaneously.

In addition to the standard alarm function of the system, a digital printout for each channel in rotation could be obtained either manually or automatically. The sample rate could be varied on automatic modes and a digital clock could be used to initiate automatic scanning of the channels at any preset period, such as once every 30 minutes. If an alarm occurred at any time, with the system in the automatic mode, the printer would automatically start printout at the alarmed channel, then scan and printout the values of the remaining channels.

Profile monitor. - The profile monitor was a commercially available 48-channel scanning system. Up to 48 millivolt signals could be connected to the input which was a mercury contact commutating switch. As the commutator rotated, each input signal was sampled and displayed as a vertical trace on a 17-inch (43-cm) cathode ray tube. The height of the trace indicated the magnitude of the input signal. With all 48 vertical input traces equally spaced horizontally across the face of the tube, the magnitude of one trace relative to another could be easily observed by comparing the heights of the traces. This unit was used to determine the liquid-vapor interface in the condenser by displaying the outputs of thermocouples on the shell of the condenser. A sample profile is shown in figure 12. The profile monitor location in the control room is shown in figure 4.

Television monitor. - A closed-circuit television system was employed to monitor conditions in the test enclosure from the control room. Two television cameras, mounted on remotely controlled swivel and tilt bases were located in the test enclosure (fig. 3)

where they would have the greatest possible sweep of the area. A 17-inch (43-cm) monitor unit with remote controls for the cameras was then located in the control room. Figure 4 shows the location of the monitor and controls in the control room.

Secondary Control-Room Area

The secondary area of the control room contained equipment which was not required for direct control of the experiment. Located in this area were the three 24-channel recording oscillographs, both thermocouple averaging systems, miscellaneous temperature monitors, 64 differential amplifiers used in the signal-conditioning system, strain gage power and balance circuitry, and a pulse output electronic clock used to time-correlate the various recording modes. This area consisted of equipment racks 21 to 28, as shown in figure 10.

CALIBRATION

Careful calibration of any instrumentation system is essential if accurate results are expected and provides confidence in the system and the data obtained. A liquid-metal system such as the SNAP-8 simulator facility presented calibration problems that were not ordinarily encountered. The high operating temperature could induce thermal errors in any of the sensors. Head effects of dense liquid metals on pressure measurements had to be considered. Calibration at operating conditions was hazardous because of the high temperatures and liquid metals. Full-range pressure calibrations in the system were impossible in some cases as the result of insufficient valving to isolate each area of the loops. Care had to be taken not to contaminate the system during calibration. Calibration of the instrumentation was carried out in two distinct phases: calibration of sensors before installation, and calibration after installation.

Calibration Prior to Installation

Thermocouples. - As noted in section II, all thermocouples and alloy extension leads conformed to ISA (Instrument Society of America) standards, and the material purchased was so certified by the manufacturer. Control-room temperature meters and meter relays were calibrated to check their accuracy and operation. Thermocouple reference ovens were adjusted to the proper reference temperature ($150^{\circ} \pm 1/4^{\circ}$ F ($339^{\circ} \pm 1/9^{\circ}$ K)) and allowed to operate several days to check their stability.

Pressure transducers. - Calibrations of all transducers to be used in the liquid-metal loops were made at room temperature and at an elevated temperature close to what each

would experience during testing. The calibration consisted of applying several pressures measured by a precision reference Bourdon tube gage and comparing the electrical output with the reference gage. A measure of the transducer temperature sensitivity was thus obtained. Every transducer was calibrated with its associated signal-conditioning unit as the electrical transmitter. Associated control-room meters for pressure indication and meter relays were calibrated for accuracy and operation. Transducers that were to be used only in the low-temperature support systems were calibrated at room temperature only.

Electromagnetic flowmeters. - Because of the high flow rates in the system, the EM flowmeters could not be calibrated with liquid metal. The manufacturers standard calibration supplied with the units was used. A much smaller EM flowmeter (one-fifth the flow capacity) used in the NaK purification loop was flow checked against the manufacturer's calibration supplied and agreed within 5 percent. A thermocouple was installed on each flowmeter to provide a temperature correction factor for the mea-

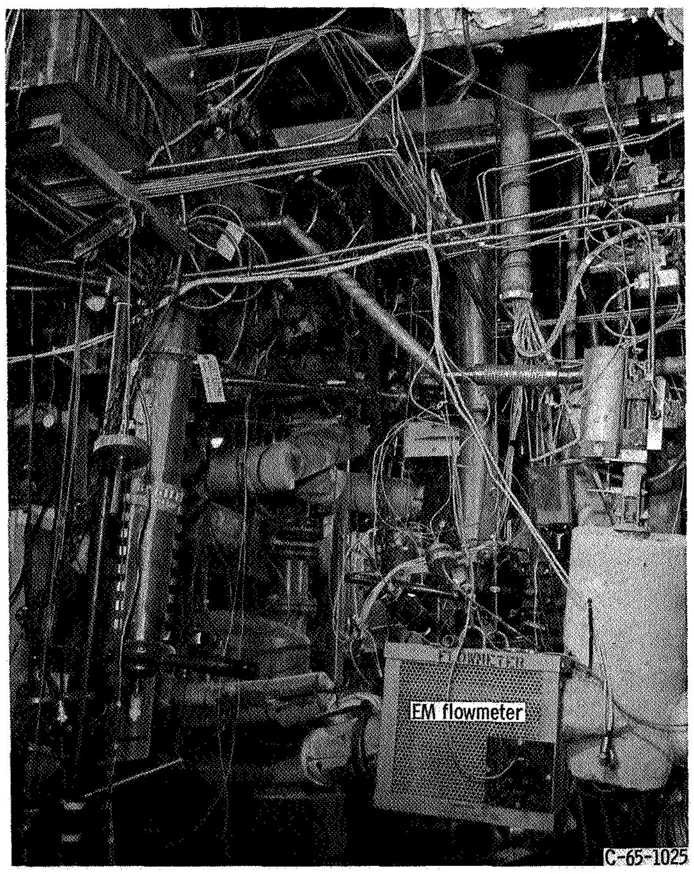


Figure 13. - Electromagnetic flowmeter installed in test facility.

sured volumetric flow. This correction factor was applied to the indicated flow on the control-room meter. The temperature correction information was supplied by the manufacturer. One of the flowmeters installed in the test facility is shown in figure 13.

Venturi. - Venturis were installed in two of the liquid-metal loops. In the NaK heat-rejection loop, one provided a check on the EM flowmeters. In the mercury loop, four were used as the sole means of measuring mercury flow: two measured liquid flow and two measured vapor flow. Water calibrations of all the venturis were checked against standard ASME flowmeters prior to installation. The vapor venturis were also calibrated in air to include choked flow conditions.

Calibration After Installation

Thermocouples. - After installation, each thermocouple circuit was checked for continuity and resistance at the input of the proper meter in the control room. A trimming resistor was then installed so that the external thermocouple circuit resistance would match the required input resistance of the meter. The thermocouple was then disconnected from the extension lead and a heated test thermocouple substituted. Observing the control-room meter for movement provided a circuit operational and polarity check. If the circuit under test did not have a control-room indicator, a test meter was used.

Pressures. - After installation in the liquid-metal loops, calibration of the transducers was limited in pressure level because of the inability of the valves to isolate various areas of each loop. Maximum calibration pressure was limited to the lowest range transducer in an isolated area in any loop. This restriction was most serious in the mercury loop where full-scale pressures ranged from 50 to 300 psia (35 to 210 N/cm^2 abs) but only 50 psia (35 N/cm^2 abs) pressure could be applied. Argon gas was used as a pressure medium for the calibrations which were performed in the same manner as the preinstallation procedure.

Flowmeters. - No calibrations of the EM or venturi flowmeters could be made after installation. Only operational checks of the EM and venturi flowmeter instrumentation were made after installation.

Other sensors. - Post-installation calibration of the valve position potentiometers was accomplished by centering the valve and potentiometer travels and taking resistance readings at both extremes of valve travel. The control-room indicating meter was then adjusted to indicate full valve travel. The oxygen and mercury vapor detectors were given only operational tests following installation.

After each test program when the liquid metal was drained from the loops, a calibration check of all pressure transducers was made in the same manner as the initial calibration after installation. No calibrations were made during operation.

DATA HANDLING, REDUCTION, AND ACCURACY

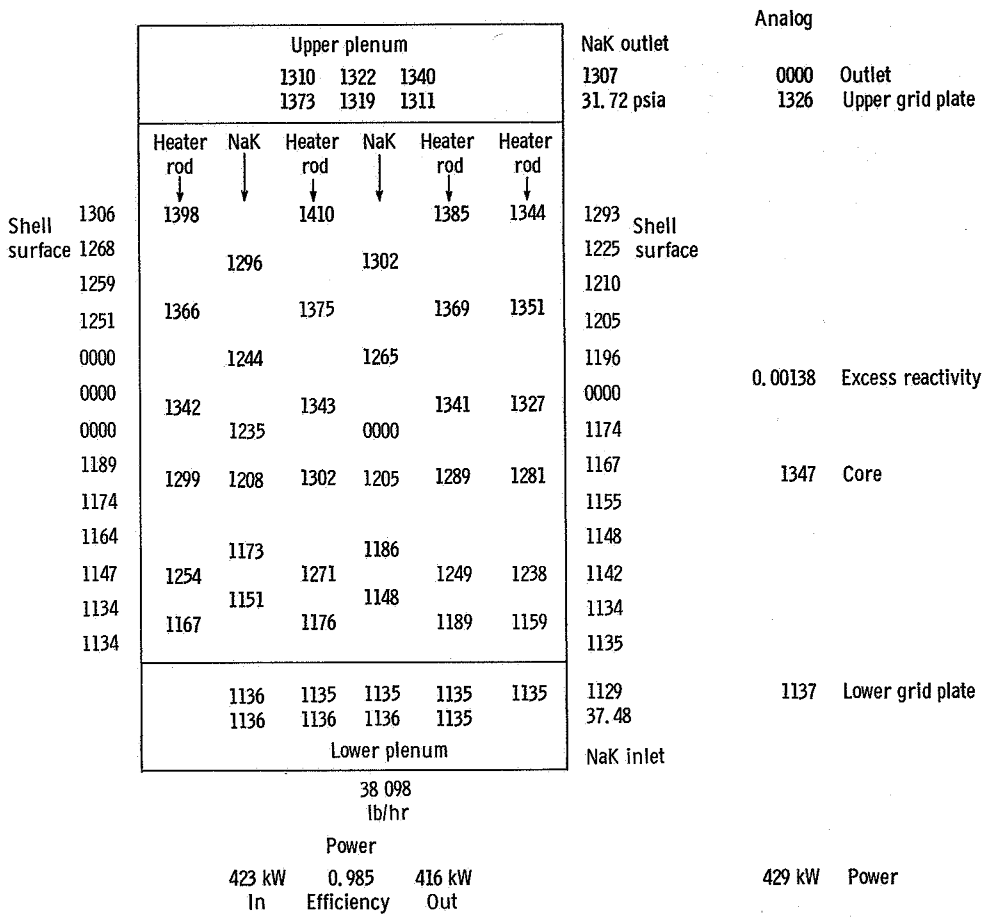
The recording of data is discussed in detail in the section RECORDING TECHNIQUES. As previously mentioned, the test data as a conditioned millivolt signal were automatically recorded on magnetic tape.

There were two basic types of data recorded: (1) a steady-state point where all the system parameters were in an equilibrium state, and (2) a transient condition where a recording was made during a change in the system operation and its resultant effect on the individual components in the system. A steady-state data point was taken by recording three complete noninterrupted blocks of the 350 channels of data. The transient data were taken by continuously recording blocks of data. For a complete system test, such as in startups, all 350 channels were continuously cycled for up to 15 minutes. An individual component test used a special patched 20-channel block which was continuously recorded for up to 20 minutes.

Method of Data Reduction

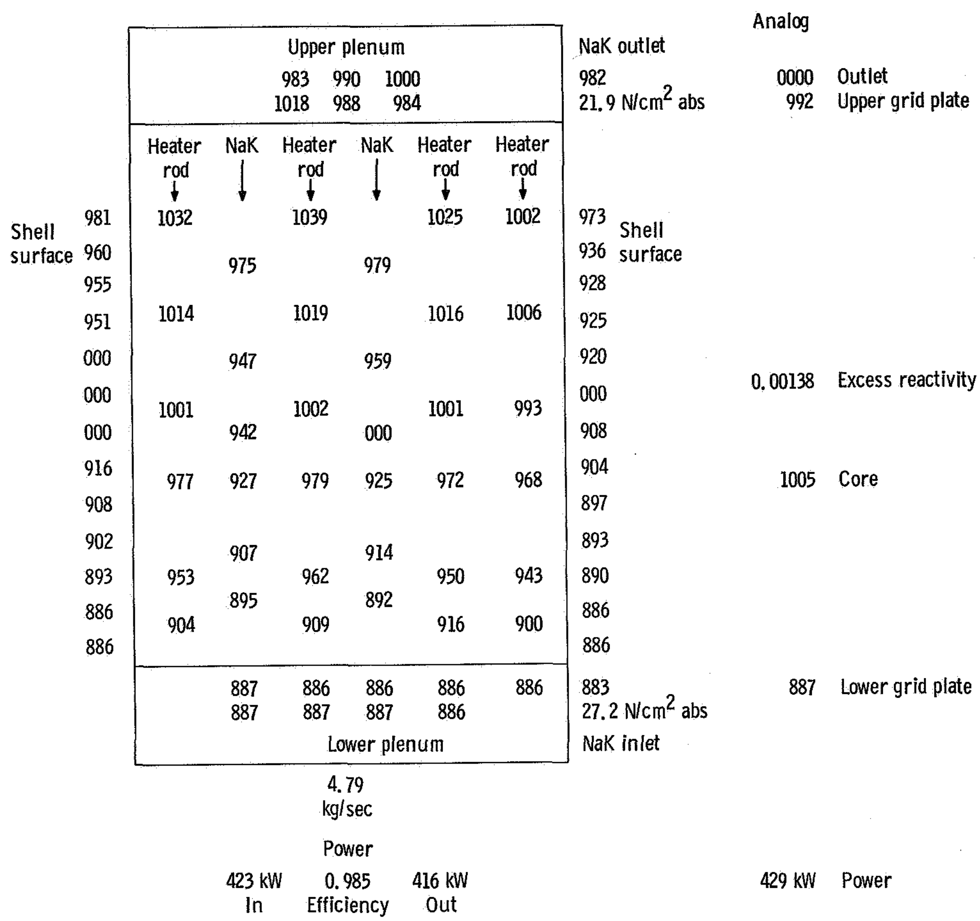
The raw data taken on magnetic tape were converted into engineering units and computed system parameters by processing on an electronic digital computer. For the steady-state data runs, the first step was to average arithmetically the three values of a given channel from the consecutive blocks. This procedure determined the most probable measured value which was then converted into either pressure or temperature through the proper calibration inserted in the computer program. At this point, flow rates were still either millivolt signals from EM flowmeters or pressures from flow venturis. The millivolt signals and the converted engineering units were tabulated in an output format of a consecutive numerical listing of channels. Of the printed output, the first five pages were the three consecutive 350 channel blocks of millivolt signals, the average of the three millivolt signals, and the converted engineering units, respectively.

System parameters such as flow rates, heat balances, thermal powers, enthalpies, and mercury flow quality were then calculated for the individual components. This information was formated in graphic form for printout to give a pictorial representation of how the system and components were performing. Samples of the parametric outputs are shown in the following figures. Figure 1 shows the general system performance of pressures, temperatures, and weight flow rates around the primary NaK heat addition loop, simulated mercury power conversion loop, and NaK heat-rejection loop. Also shown are thermal powers and efficiencies associated with the various components. Figure 14 shows both the internal and external temperature distribution of the NaK heater as measured. Also included in this figure are the simulated reactor numbers from the analog computer which controlled the heater.



(a) All numbers are temperatures in °F unless otherwise specified.

Figure 14. - NaK electric heater temperature and analog reactor profiles in computor output format.



(b) All numbers are temperatures in °K unless otherwise specified.

Figure 14. - Concluded.

Component Performance

Experimental data needed for component performance were put on a calibrated tape. This tape was made by processing the raw millivolt data through the computer to average the three signals from each channel and converting the average into engineering units. The calibrated tape was used in a special computer program which put the boiler and condenser temperature profiles on another tape in a mode which allowed them to be plotted as curves on graph paper from a numerically controlled printer plotter.

Figure 15 shows a sample of three vertical temperature distributions on the outsides of the inner and outer shells of the mercury boiler. Each point is plotted as a function of temperature against the distance along the mercury tubes starting at the tube inlet. Figure 16 is a machine plot of the NaK and outer shell temperature distribution along the tubes of the SNAP-8 condenser. Temperature profiles shown are one outside NaK shell, two NaK immersion, and two mercury profiles. The mercury profiles were calculated by assuming a constant condensing temperature based on mercury inlet saturation pressure and calculated from a heat balance with the NaK immersion temperatures.

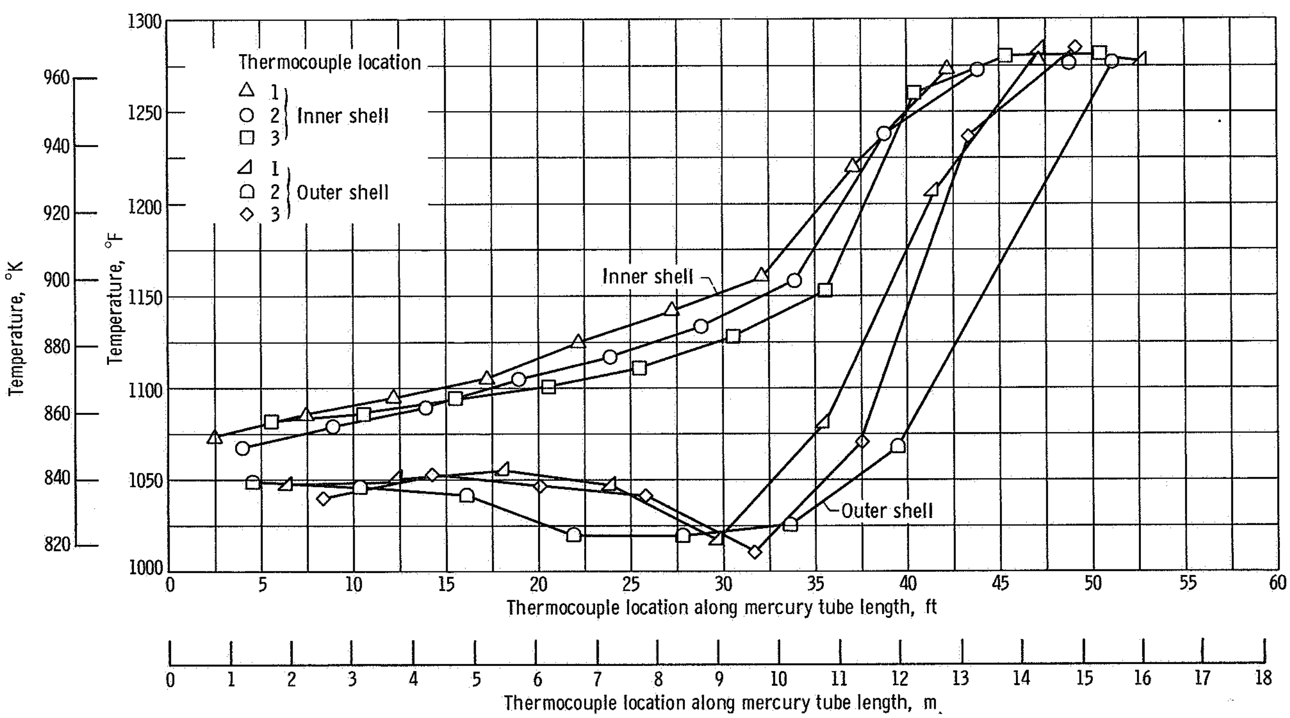


Figure 15. - Boiler vertical temperature distribution machine plotted as function of thermocouple location along mercury tube from inlet.

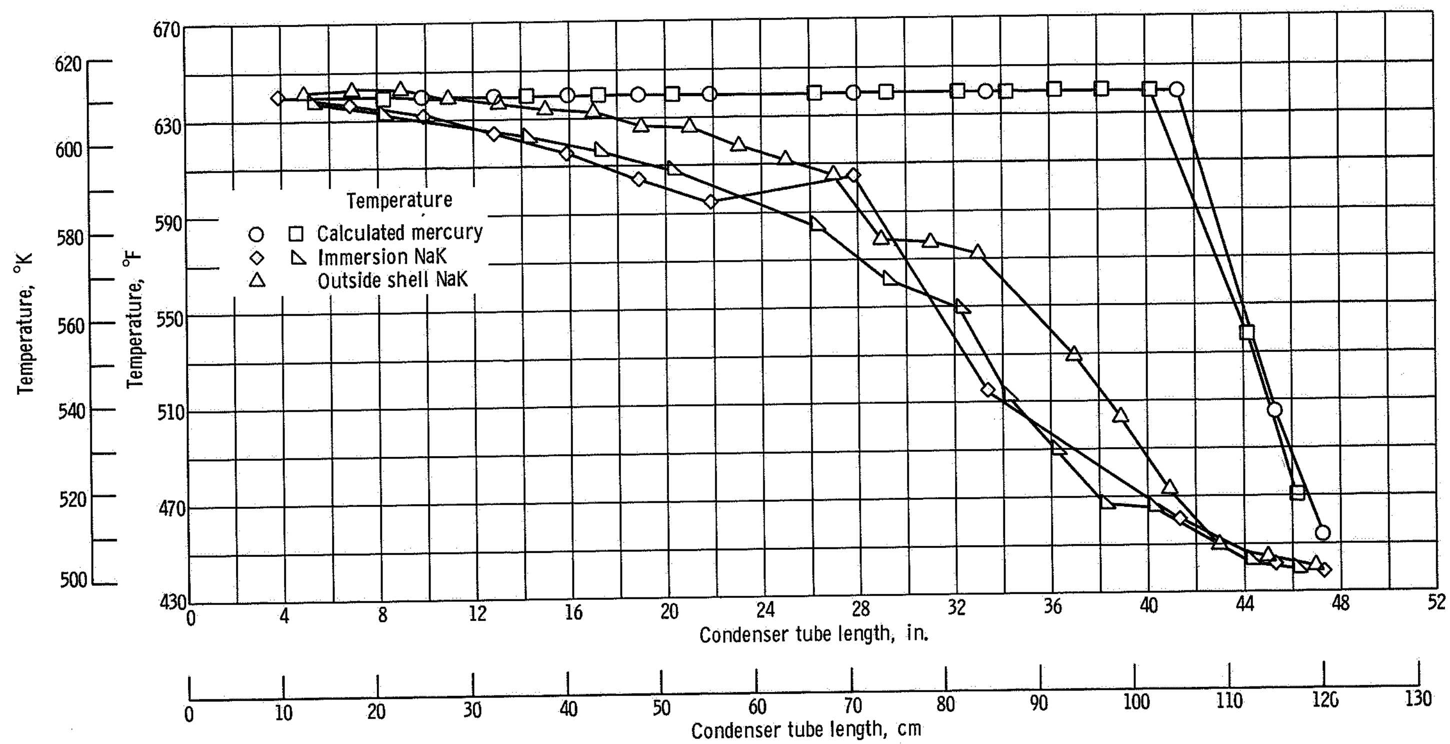


Figure 16. - Condenser temperature distribution as function of distance along tube from inlet.

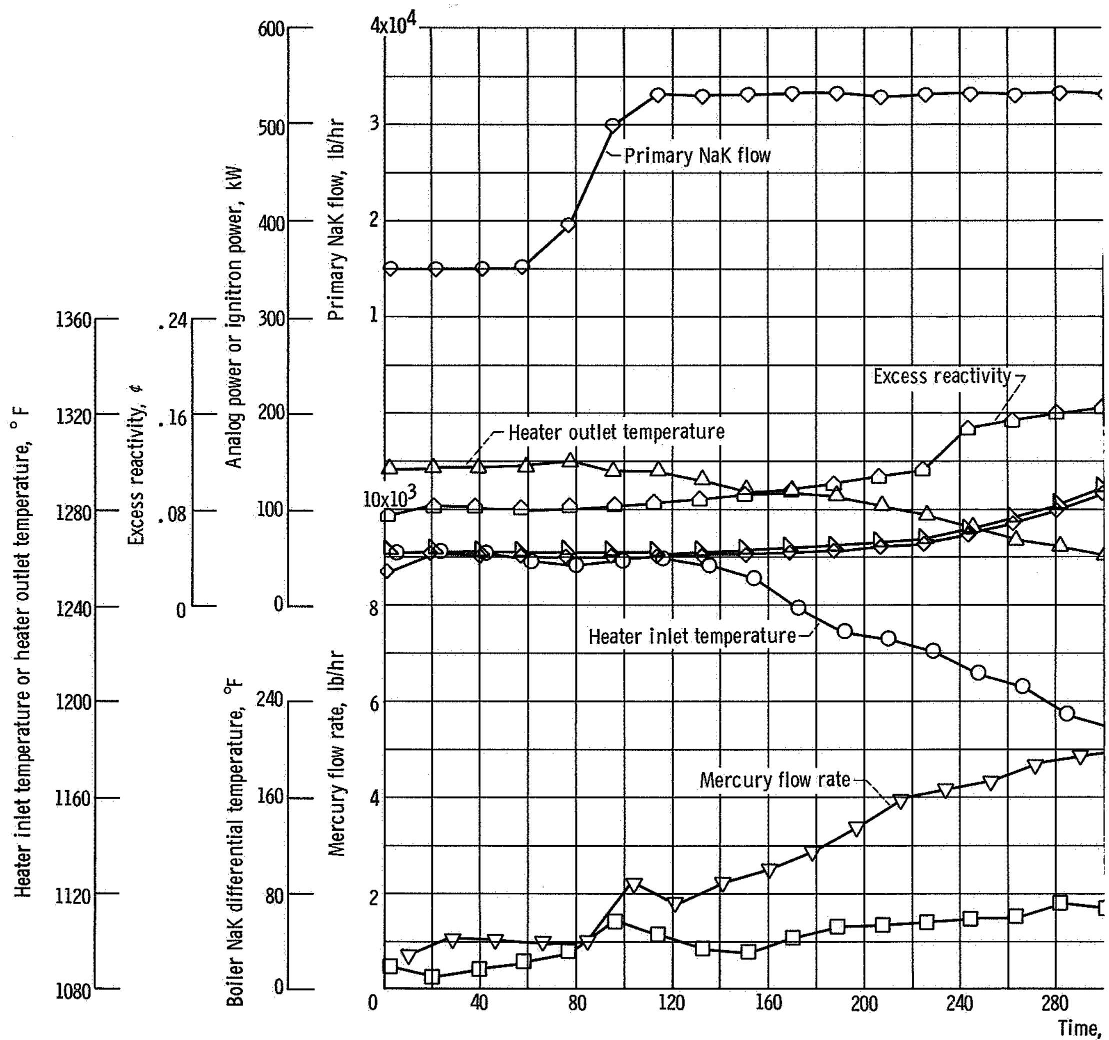
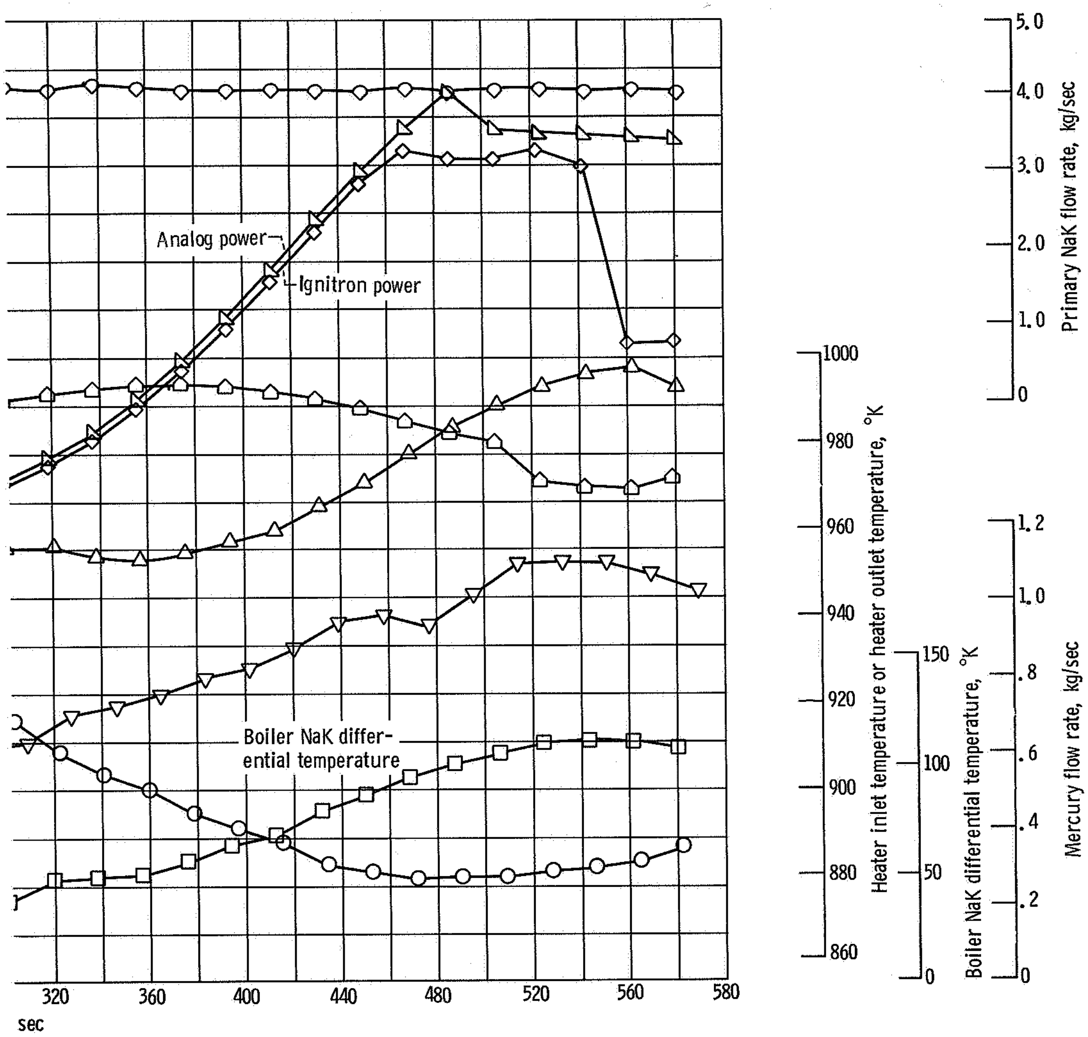


Figure 17. - Digital plot of typical



mercury flow startup transient.

Transient Data

Two basic types of digital transient data were taken. The first was data from the complete system and recorded the perturbations due to startup of mercury flowing through the system. A complete set of data was recorded by continuous repeated cycling of all the 350 instrumentation channels for up to 15 minutes. Each pertinent channel and calculated flow parameter was plotted in real time by use of the digital computer and printer plotter. A given channel was recorded about once every 30 seconds, and, in order to show trends, the data points were connected with straight lines. It is recognized that step changes cannot be recorded on this digital plot and that the results must be interpreted on this basis.

Figure 17, a typical mercury flow startup for approximately 10 minutes, shows the parameters mercury flow rate, ignitron power, excess reactivity, heater NaK inlet and outlet temperature, analog power, primary NaK flow rate and NaK ΔT across the boiler. Most of the data shown in figure 17 were also taken on continuous strip-chart recorders in the control room, which recorded a true transient response. Shown in figure 18 are four of the eight curves in figure 17 taken during the same time interval. There are obvious advantages and disadvantages to both types of curves. The continuous strip-chart recording gives the true response of a transient but has to have its chart span and speed predetermined and set before the actual recording. Digital data, unless recorded at a rapid rate, will not indicate exactly when changes took place because of the finite time interval between data points taken. However, the scaling programmed on the digital printer plotter can be changed to produce any size curve after the data have been run.

The second type of data for component transient response to system perturbations was obtained by continuously cycling a specially patched block of 20 channels for as long as 20 minutes. These data were also converted into engineering units and put on a special tape to be used in a program for the digital printer plotter. Since each channel is recorded about every second, all data for a complete cycle are plotted as occurring at the same time. The error-due-to-time difference between channels is neglected. An example of this is shown in figure 19, which shows the boiler parameters responding to a near step change in mercury flow rate. The parameters shown are heater electrical power input, NaK flow rate, NaK outlet temperature, two mercury outlet temperatures, NaK inlet temperature, mercury flow rate, and mercury outlet pressure. The points for each channel are connected with straight lines to form a reasonable continuous curve.

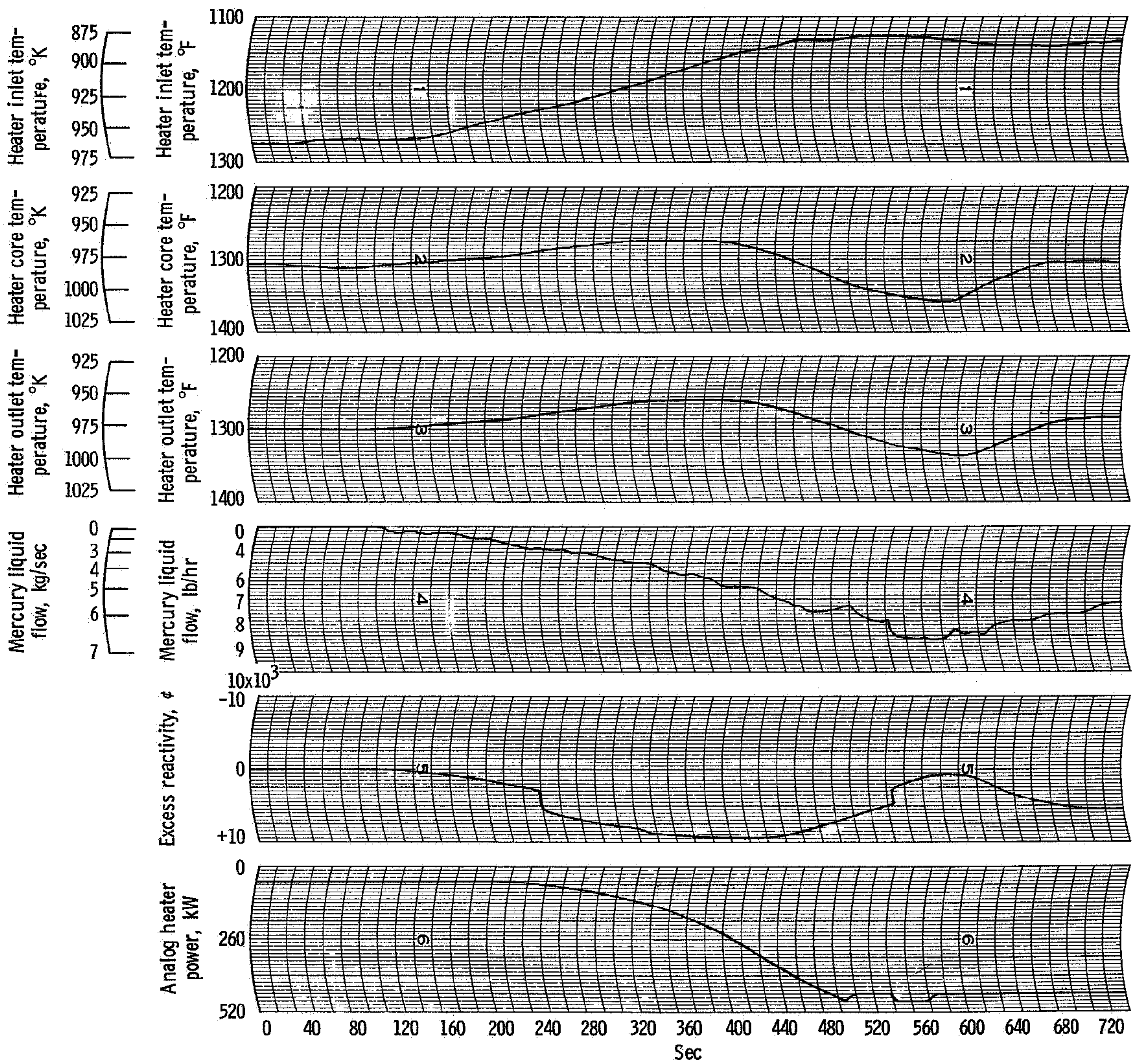


Figure 18. - Continuous strip-chart recording of typical mercury flow startup shown in figure 17.

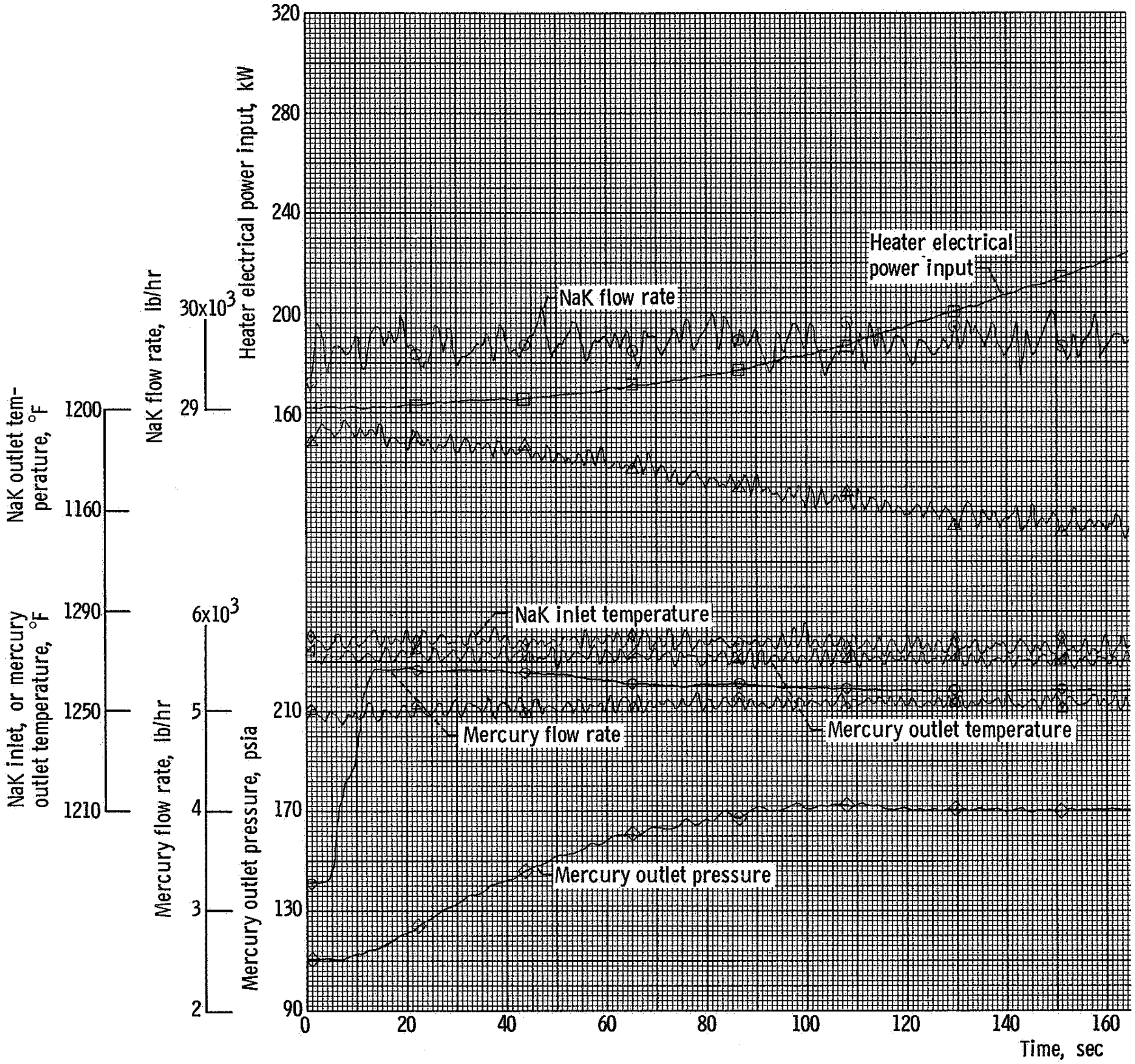
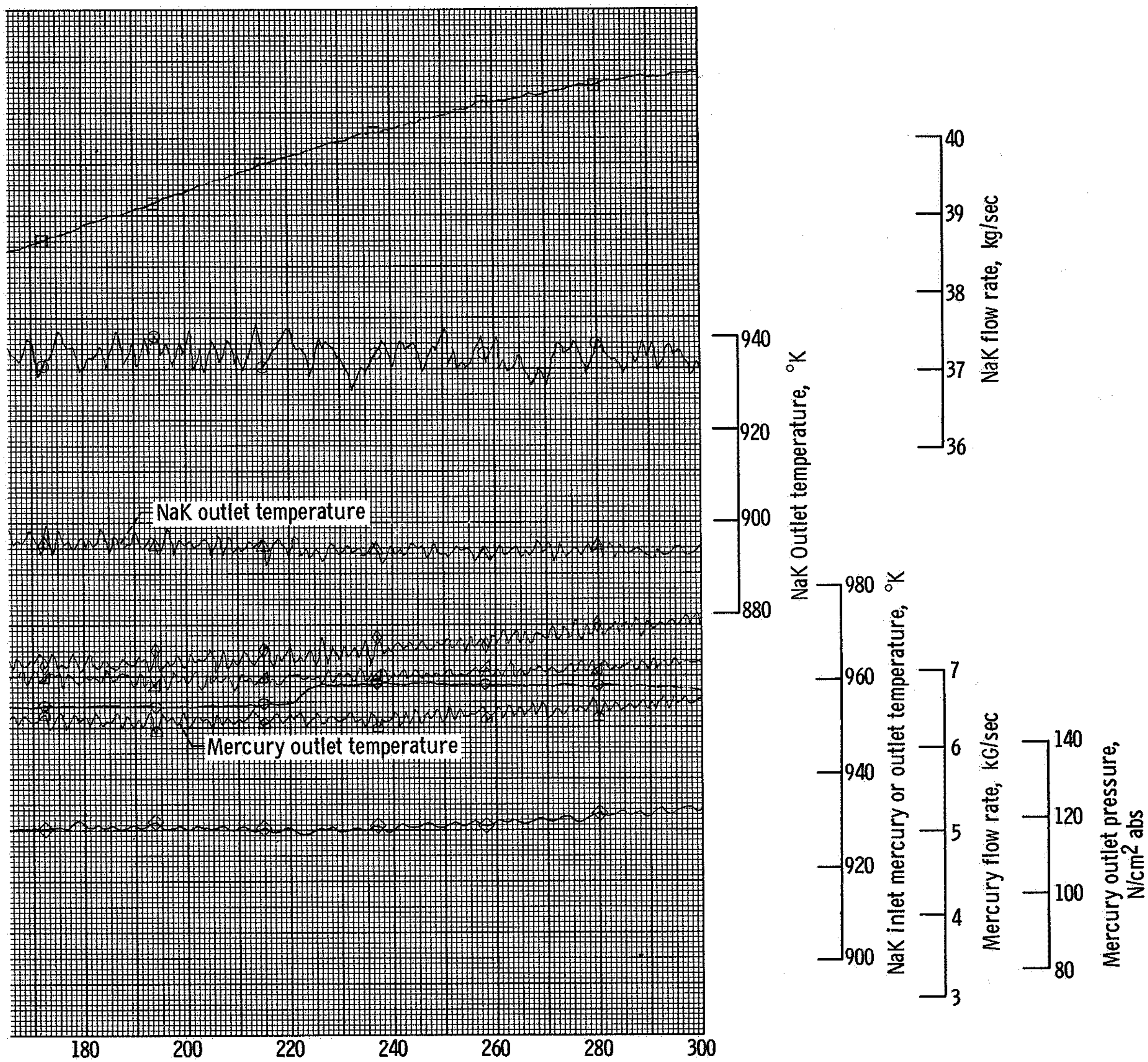


Figure 19. - Digital plot of effect on boiler parameters due to



transient step change in mercury flow rate.

Experimental Accuracy of Computed Results

The accuracy of directly measurable quantities (pressures and temperatures) after instrument calibration is dependent on the deviation of the individual channel measurements from the most probable measured value (the average of the three values for a given channel). Ten representative steady-state data runs out of 1000, covering a time period of 750 hours of operation, were selected to determine engineering value deviations. Maximum deviations of the most probable measured value (the average of three repetitive values) were averaged to give a representative value for a given channel. It was noted from the data of the 10 runs that the maximum deviation of any channel occurred at random with respect to the runs. For a given type of similar instrumentation, the average maximum deviations per channel were averaged to give one gross value which was taken as representative. This overall average value as a percentage along with the actual value of the maximum deviation and its percentage of that particular signal are listed in the following table for the various types of instrumentation:

Instrument signal	Average deviation, percent	Maximum deviation, percent	Maximum deviation
Thermocouple	0.15	0.35	3.5° F (2° K)
Electric power	.15	4.00	14 kW
EM flowmeter	.44	1.25	400 lb/hr (0.05 kg/sec)
Absolute pressure	.32	1.20	1.6 psi (1.10 N/cm^2)
Differential pressure	.30	12.3	1.5 psi (1.03 N/cm^2)

For engineering quantities $Q = f(A, B, C, \text{etc.},)$ which are calculated by using a combination of measured values, there is an error, usually larger than any individual error, called the most probable computed error ΔQ. This error is obtained by taking a first-order partial differential of each of the measured quantities with respect to the computed quantity and summing to give

$$\Delta Q = \frac{\partial Q}{\partial A} \Delta A + \frac{\partial Q}{\partial B} \Delta B + \frac{\partial Q}{\partial C} \Delta C$$

where ΔA, ΔB, and ΔC are the most probable measured errors. Some of these errors as a percentage are

EM flow, percent	0.8
Venturi flow, percent	0.7
Thermal power, percent	6.0

DISCUSSION

The test facility was operated for approximately 2000 hours at elevated temperatures. During this time, the maximum continuous operation without interruption was about 450 hours. Almost 1000 hours of operation at temperature were accumulated on the mercury loop during which time there were 41 startups of the mercury loop with the NaK loops at temperature. Most of the 2000 data recording runs were taken as a documentation of operational history on an hourly basis.

Of more than 600 active thermocouples in service in the facility, less than 3 percent failed completely. One-third of the failed thermocouples were traceable to being damaged before the facility became operational. Because of this low failure rate, the installation and fabrication techniques were considered reliable for long-term liquid-metal operation.

There were approximately 500 thermocouple channels in the reference ovens, six of which failed during the test operation. The reference temperature (150° F (339° K)) of the nine ovens was checked daily. Over the entire operating time of 2000 hours, the maximum reference temperature shift was from 1 to 3° F (0.5° to 1.5° K) low. Changes in the reference temperature due to the on and off mode of the oven heater for temperature regulation were less than $\pm 0.2^{\circ}$ F ($\pm 0.1^{\circ}$ K).

A slack-diaphragm - capillary-tube pressure transducer failed in the mercury loop after 500 hours of operation as the result of a crack in the diaphragm. Two high-temperature strain-gage pressure transducers in the mercury loop failed because of an accidental overpressurization of the condenser. Two variable reluctance transducers failed as the result of internal electronics and leaks. After 250 to 1000 hours of operation, calibration change with time of pressure transducers used for digital recording of data was random as shown in the following table:

Transducer type	Quantity	Change	Maximum change
Slack diaphragm with capillary tube	9	No significant change	1 percent
	7	Slope change	1 at 17 percent
	6	Zero shift	1 at 1.5 percent of full scale
	1	Failure	--------------
Variable reluctance	1	No change	--------------------
	8	Slope change	2 at 4 percent each
	1	Zero shift	4 percent of full scale
	2	Failures	--------------------

For the slack-diaphragm - capillary-tube transducers, the slope change occurred near a point from one-third to one-half of full scale. Actual error in the measured value was less than the percentage slope shift because the point about which the slope changed was near the operating point being measured. The one slope change of 17 percent and another of 10 percent caused an error in the measured value that was less than one-half the slope change. Other slope changes were less than 5 percent. The variable-reluctance pressure transducers were operated primarily at ambient temperatures. Slope changes were random and occurred around any location of the full-scale curve.

No problems were encountered with the EM flowmeters. In the NaK heat-rejection loop, the venturi flow generally agreed with the EM flow within 5 percent. Venturis used in the vapor region of the mercury loop showed severe erosion of the metal at their throats (ref. 1). Water calibration of the vapor venturis after final facility operation showed that their discharge coefficients decreased by about 20 percent. For the two mercury liquid venturis, the discharge coefficient decreased by about 2 percent. The venturi in the NaK heat-rejection loop had no change in its discharge coefficient.

The light-beam oscillographs as secondary recorders operated satisfactorily but proved to be time consuming in changing input signals and calibrating. Response capability of the oscillographs was far greater than required. The use of a profile monitor to indicate the mercury vapor-liquid interface in the condenser (fig. 12) proved to be a useful operational tool in helping to set test conditions in the mercury loop. No difficulties were encountered in its operation. Operation of an electric heater controlled by an analog computer to duplicate the characteristics of a nuclear reactor was successfully demonstrated (ref. 2).

Although there was an extremely large amount of alternating-current electric power used throughout the facility, no significant interference with the instrumentation

system was observed. Confirmation of this fact was made by looking at the individual data channels on an oscilloscope and by examining the data records from CADDE and the secondary recorders. The lack of interference was obtained by using all shielded cables properly grounded for each sensor, and by routing all instrumentation cables in separate conduits and trays from the electrical power wiring.

Use of CADDE reduced an impossible task of hand recording data to one which allowed taking more than 3 million bits of data. Without use of the digital computer to compute parameters and process data for the digital printer plotter, more than 10 man-years of manual work would have been required for the computations and plotting. Over 10 man-years of effort went into analyzing the data and writing reports. Reports published to date are listed in the references.

CONCLUDING REMARKS

A three-loop liquid-metal system was operated for over 2000 hours. During 2000 hours of operation, more than 2000 data points were taken each involving more than 700 individual measurements of temperature, pressure, and flow rates. The following factors in selection and installation of the instrumentation were considered crucial for such a test program:

1. Stable, rugged, low-response-rate pressure and flow sensors were used to obtain basic data. Where more complete information was required, the basic data sensors were supplemented with high-response-rate, less rugged units.
2. Backup, visual, steady-state pressure indicators were installed at all critical locations.
3. The process side of all pressure sensors installed on NaK lines was operated as near to the temperature of the NaK in the line as possible, in order to minimize plugging problems.
4. Pretest and post-test calibrations were made of sensors.
5. Wiring was routed to minimize damage in the event of a liquid-metal fire.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 31, 1967,
701-04-00-02-22.

REFERENCES

1. Valerino, Alfred S.; Wood, James C.; and Reznik, Joseph F.: SNAP-8 Simulator Loop Mechanical Design. NASA Technical Memorandum, estimated publication, approximately Jan. 1968.

2. Jefferies, Kent S., Packe, Donald R.; and Dittrich, Ralph T.: Design and Performance of a Nuclear Reactor Simulator for Nonnuclear Testing of Space Power Systems. NASA TN D-4095, 1967.

3. Thollot, Pierre A.; Block, Henry B.; and Jefferies, Kent S.: Experimental Investigation of Reactor-Loop Transients During Startup of Simulated SNAP-8 System. NASA Technical Note, estimated publication, March 1968.

4. Albers, James A.; Wintucky, William T.; and Gorland, Sol H.: Conditioning and Performance of SNAP-8 Tube-in-Shell Mercury Boiler. NASA TM X-1441, 1967.

5. Soeder, Ronald H.; Curreri, Joseph S.; and Macosko, Robert P.: Performance of a Multitube Single-Pass Counterflow NaK-Cooled Mercury Rankine-Cycle Condenser. NASA Technical Memorandum, estimated publication, approximately March 1968.

6. Schoenberg, Andrew A.; Bilski, Raymond S.; and Thollot, Pierre A.: Theory and Testing of a Space Radiator Simulator for a SNAP-8 Ground Test Facility. NASA TM X-1375, 1967.

7. Jackson, Carey B.; ed.: Liquid Metals Handbook. Sodium-NaK Supplement. Rep. No. TID-5277, AEC and the Bureau of Ships, July 1, 1955.

8. Siev, Robert: SNAP-8 Instrumentation. Preprint 1. 11-4-65, Instrument Society of America, October 4-7, 1965.

9. Dittrich, Ralph T.; and Lynch, Michael P.: Bimetal Sensor for Averaging Temperature Measurement of Nonuniform Temperature Profiles. NASA TN D-4242, 1967.

10. Staff of the Lewis Laboratory: Central Automatic Data Processing System. NACA TN 4212, 1958.

NASA-Langley, 1968 —— 14 E-4038

National Aeronautics and Space Administration
WASHINGTON, D. C.

OFFICIAL BUSINESS

FIRST CLASS MAIL

POSTAGE AND FEES PAI
NATIONAL AERONAUTICS A
SPACE ADMINISTRATION

POSTMASTER: If Undeliverable (Section 1
Postal Manual) Do Not Ret

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—National Aeronautics and Space Act of 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546